University of Alberta

Diversity and seasonality of tropical spiders in cacao agroforestry systems of North Sulawesi, Indonesia

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Biology and Ecology

Department of Biological Sciences

Edmonton, Alberta

Fall 2007

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ISBN: 978-0-494-33285-6
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ISBN: 978-0-494-33285-6

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Biological diversity is the key
to the maintenance of the world
as we know it.
Life in a local site struck down
by a passing storm springs back quickly:
opportunistic species rush in to fill the spaces.
They entrain the succession that circles back
to something resembling the original state of the environment.
If it is granted that biodiversity is at high risk,
what is to be done?
The solution will require
cooperation
among professions long separated
by academic and practical tradition.
(Edward O. Wilson)

Dedicated to

my mother, Betsy, and my late father, Daniel

Abstract

Traditional approaches to cacao cultivation under shade have been recognized for their ability to protect biological diversity of species. Conversion of the traditional forest cacao farms to intensive, full-sun monocultures have negative impacts on spider assemblages and, by extension, overall biodiversity. Pitfall traps were established in a systematic sampling array in four different cacao cropping systems in North Sulawesi, Indonesia from January 2001 to May 2002. Spiders were also sampled from the vegetation using modified insect sweep nets. I found that spider diversity increased with an increase in both floristic and structural diversity of the cacao shade level. Seasonality in tropical spider assemblages and individual species was also influenced by cropping system. It is clear that the traditional shaded cacao agroforestry system is one of the few productive agricultural systems that can sustain a diverse tropical spider assemblages.

Acknowledgements

This project was initially funded by the Canadian International Development Agency (CIDA) through the Eastern Indonesia Universities Development Project (EIUDP). I would like to thank EIUDP awarding me a four year scholarship support to study at the University of Alberta. I also thank Dr. Don Kvill, Canadian Program Manager and Advisor at the University of Haluoleo (UNHALU) Kendari, Southeast Sulawesi, who selected me to get this funding. Thanks to UNHALU Kendari for allowing me to take a leave and paid my Indonesian salary during my study.

I thank Dr John Spence for accepting me as his student and providing me the opportunity to learn both field and lab work which were essential for my work in Indonesia. I deeply appreciate him for his inspiration, encouragement, compassion, and tender loving care as well as financial support during the most difficult time when I had to face unexpected challenges both as an International student and a new and single mother. Moreover, my applications to renew my study permit during the unusual length of my program was always approved by Immigration Canada because of his powerful letter of support. I would also like to thank my committee, Dr Fiona Schmiegelow, Dr Bruce Heming and Dr Robert Holmberg, for guidance and comments on the final thesis. Thanks to Dr Robert Holmberg for supporting me with references related to my work. Thanks to Don Buckle for verifying the identification of some families of tropical spiders. Spence lab members from when I started my study to the present always provided support. Chris Buddle, Dave Shorthouse and Alice Graham trained me in the identification of boreal spiders. Carol Frost helped me in the identification of tropical spiders. Karen Cryer provided a steady supply of lab work. Nik Tatarnik provided the Global Positioning System (GPS) information. Dave Shorthouse contributed to the statistical analysis in an earlier version of this thesis. Chris MacQuarrie contributed to one figure of this thesis. A special thanks to Joshua Jacobs who contributed to the statistical analysis and to the figures in the final version of this thesis, and provided constructive comments during the writing of the thesis.

I thank the Department of Biological Sciences at the University of Alberta for supporting me with a Graduate Teaching Assistantship (GTA) and Casual Teaching Assistantship (CTA) when my sponsorship with EIUDP-CIDA ended. I thank Maggie Haag for assigning me in this teaching program. Thanks to Dr John Chang who agreed that the Dept of Biological Sciences support me during my maternity leave. Thanks also to the Graduate Student Ombud Service and Graduate Student Association that fought for my right to get paid during maternity leave. I would also like to thank Angela Anderson and Sherri Xie, International Student Advisors, for guidance in the resources for international students and immigration issues during difficult times.

I am also grateful to the Church in Edmonton for financial support when I had no support. I thank brothers and sisters in the church especially Allen and Lo Ann Liu, Rod and Cathie Mattingsley, Bill and Linda Sakellariou, Tom and Michelle Noga, Bing Xiao and Mei Li, Laura Forestier, Daisy Wong, Julia Lee, and Cyrine Bation for helping me and my son in many ways in the past few years. A special thanks to Jo-Dell Forestier who helped babysitting my son for the last two months days and nights during the writing of my thesis.

The day-to-day logistics for my field work in North Sulawesi, Indonesia were extremely challenging. Ferdinand Pangemanan, Novly Kuhu, Maxie Koropit, and Agus Sumolang are four truly amazing field assistant. I thank them for all their help in the field. I also thank the owners of the private cacao estates in Kima, Paniki, and Pungkol, and the state cacao estate in Tiniawangko for permission to conduct my research in their fields. Thanks to my aunt Luisa Korinus who provided free accommodation during my field work.

I thank Dr. D.T. Sembel, B.Agr.Sc. , Dean of the Faculty of Agriculture, who supervised my field work when I started it, and Dr. J. Warouw, Dean of the Faculty of Graduate Studies University of Sam Ratulangi (UNSRAT) Manado, North Sulawesi, who provided an official letter to get permission to conduct the research in the cacao field and to obtain information from weather stations, state plantation services and related government offices. Thanks to Drs. Alamsyah,

M.S. , Dean of the Faculty of Science UNHALU Kendari, who provided an official letter to get permission to bring spider specimens of North Sulawesi to Canada.

I would especially like to acknowledge my parents, my mother Betsy and my late father Daniel, my brother Agus, my sisters Maria and Juli for encouraging me during my study. I grieved deeply for not being able to see such a wonderful father while he was still carrying the gift of life. I thank my husband, Benny Marthin, who sent his sister from Indonesia to Edmonton, to help babysit our son for 9 months in 2004. I thank my sister-in-law, Fera Marthin, for her help. Finally, on top of all this, I give thanks to the Lord for giving us the most precious gift, Giovanni Marthin, our beloved son, and for guiding me through all the difficult situations.

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Chapter 1 General Introduction

1.1 Introduction

Cacao (*Theobroma cacao* L.) is a crop originally planted in natural tropical forest habitats. The natural shade trees-cacao system supports higher levels of biological diversity than most other tropical crops. The agroforestry approach of shaded cacao plantations can support local species diversity within the same order of magnitude as that of undisturbed forest (Perfecto *et al.* 1996; Rice and Greenberg 2000; Philpott and Armbrecht 2006). As cacao has been a lucrative and globally traded cash crop for tropical farmers, it is economically important in SE Asia (Rice and Greenberg 2000). The many negative environmental effects of converting natural and semi-natural forest habitats to modern agriculture have been reviewed by Krebs *et al.* (1999). The growing concern about this matter has been exacerbated by the global move to conserve biological diversity and develop more sustainable agriculture. In the next section, I provide a brief introduction to cacao, cacao agroforestry systems in North Sulawesi, Indonesia and the importance of conducting the study on spider diversity in these systems.

1.2 Introduction to Cacao

Cacao is a tropical plant indigenous to the Amazon basin and other tropical areas of South and Central America (Wood 1985, Beckett 2000, Motamayor *et al.* 2002). The tree's earliest known name, "kakawa," came into use among the Olmec, the people of the Mexican Gulf Coast who built the first of the great Mesoamerican civilizations ca. 1000 B.C. In about 400 B.C.–A.D.100 the Maya of Northern Guatemala adopted the word "cacao" from the Olmec (Coe and Coe 1996, Cocoa 2005). The word chocolate derived from the Mayan "xocoatl," and cocoa from the Aztec "cacahuatl." The chocolate-related term "cacahuatl" is "nahuatl," derived from Olmec/Mayan etymology (Dillinger *et al.* 2000). The Mexican Indian word "chocolate" comes from a combination of the terms "choco" (foam) and "atl" (water). The plant's scientific name, *Theobroma cacao*, was given by Swedish botanist Carolus Linnaeus in 1753 and is derived from the

ancient Greek words for "god" (Theo) and "food" (broma), food of the gods (Coe and Coe 1996).

The cacao tree is the only one of 20 species in the genus *Theobroma* that is cultivated widely. The trees are relatively small, 12 - 15m in height, and grow naturally in the lower level of the evergreen rainforest. They can live up to 100 years. The leaves are bright green, about 15cm long and 8cm wide. Flowers and pods grow from the stem or from main branches. Trees start bearing pods after 2 to 3 years, but it is 6 or 7 years before they give a full yield. The pods can be up to 30cm long but their sizes can differ significantly. The pods normally weigh 300g – 500g and are red-brown in colour. The fruit grows to full size in about 5 months and ripens over another month. Its pulp is often eaten by animals and its seeds are used for chocolate. There are 20 – 40 seeds or beans in one pod.

Best growth for cacao requires relatively warm temperatures varying between 21°C to 32°C and significant rainfall that is not highly seasonal. Cacao trees have been moved around the world and are now grown in many tropical forests within 20° of the equator. These areas have a high average temperature ($\geq$ 27°C) throughout the year and a constant high humidity, arising from a plentiful rainfall (1,500 – 25,000mm/yr).

The three main varieties of cacao are criollo, forastero and trinitario. Criollo, the prince of cacao, originates from South America, mainly Venezuela, where it is mostly still grown today, accounting for only a small part of the world crop. Its pods are smaller and have a soft thin skin. The ground seeds ('beans') have a light color and a unique pleasant aroma associated with what is considered as high quality taste. Despite its small market share many consider it to produce the best cacao. Forastero is easier to cultivate, and thus is the dominant variety of cacao worldwide, accounting for over 80% of world cacao production. Most of the production comes from Africa. This variety has a thick-walled larger pod and the seeds have a pungent aroma. The taste quality ranges from very low to quite complex and desirable. The highest quality strains come from Ghana, Java and Ecuador. Trinitario comes almost exclusively from Trinidad, and is believed to be

a hybrid of criollo and forastero. It has a stronger, more full bodied flavor than criollo. The taste quality can be very good and highly complex (Wood 1985, Beckett 2000). Cacao is economically important because it is the raw material base for numerous highly valued consumer products. The most important producers of cacao are Brazil, Cameroon, Ecuador, Ghana, Indonesia, Ivory Coast, and, Nigeria (FAO 2007) .

Cacao refers to the domesticated plant and all its products, before processing. Cacao beans are the source of all chocolate and cocoa. They are found in the pods of the cacao plant. Cocoa is the de-fatted powder made from cacao beans. Chocolate is produced by processing the beans of the cacao plant, whether in liquid or solid form. Dark chocolate is chocolate that contains more than 50% cocoa content. Besides chocolate liquor, it often contains cocoa butter, sugar, vanilla, and lecithin. Milk chocolate is chocolate liquor to which dairy products, sugar, vanilla and lecithin have been added (Kara Chocolates 2005, Burdick 2006). High quality milk chocolate should contain a minimum of 30% of chocolate liquor, ≥12% of total milk solids, and ≥3.39 % milk fat (Morgan 1994). White chocolate is made from cocoa butter, dairy, sugar, vanilla and lecithin. It does not contain chocolate liquor but must contain at least 33% cocoa butter to be considered of good quality (Kara Chocolates 2005, Burdick 2006).

1.3 Cacao Cultivation in Sulawesi

The earliest known introduction of cacao into Asia was in 1560. The first recorded tree was brought to the Island of Sulawesi, Indonesia, from Caracas, Venezuela. In 1778 the Dutch brought cacao from the Philippines to Jakarta and Sumatra, where they established a propagation facility that soon led to major production in the Dutch East Indies, now Indonesia and Malaysia (Wood 1985, Cocoa 2005). From the 1980s to the 1990s about 50% of the present cacao-growing area in Sulawesi appeared in formerly forested areas (Rice and Greenberg 2000). Cacao cultivation has expanded by 230% in the last two decades, triggered by economic and cultural factors (Steffan-Dewenter *et al.* 2007).

1.4 The Economic Importance of Cacao

Cacao is economically important to Indonesia. Of the 11,636,000 ha devoted to industrial agriculture in 1995, cacao accounted for 543,000 ha. This placed cacao as the fifth main industrial crop in the country after coconut (3,712,000 ha), rubber (3,392,000 ha), oil palm (1,648,000 ha) and coffee (1,148,000 ha) (Central Bureau of Statisics 1997). Presently, cacao is one of the big five industrial crops of North Sulawesi, a province of Indonesia. Among three regencies in North Sulawesi, growers in Minahasa devote the third highest area to cacao plantations, after Sangihe Talaud and Bolaang Mongondow, respectively. In 2001, the total area of small-holder plantations, state owned estates, and private estates devoted to agriculture in North Sulawesi was 340,610 ha. Cacao occupied 7,310 ha or only 2.15 % of total plantation area, after coconut (262,930 ha), clove (40,610 ha), nutmeg (16,870 ha), and coffee (7,508 ha). However, between 2000 to 2001 there was an increase of 1,384 ha in area of cacao plantations in Minahasa alone. Nevertheless, the total production of cacao decreased from 1,776 tons in 1999 to 1,070 tons in 2001 (Central Board of Statistics 2001; North Sulawesi Plantation Services 2002). This trend is consistent with the slight decrease in total production of cacao in Indonesia from 390,000 tons in 1999 to 385,000 tons in 2001 (ICCO 2001).

Cacao is the second most important tropical cash crop, cultivated on 6,990,000 ha with a world production of 3,881,000 tons. In 2004, total production of cacao in Indonesia was 601,000 tons or 15.49 % of total world production. This placed Indonesia as the third largest world production country after Ivory Coast and Ghana (Table 1-1)(FAO 2007).

Table 1-1 Cacao beans and percent of world production represented by country, 2004. Source: FAO, 2007

Country	Cacao beans (1000 tons)	% World cacao production
Brazil	195	5.02
Cameroon	167	4.30
Colombia	51	1.31
Dominican Republic	47	1.21
Ecuador	124	3.19
Ghana	736	18.96
Indonesia	601	15.49
Ivory Coast	1331	34.3
Malaysia	33	0.85
Mexico	48	1.24
Nigeria	366	9.43
Papua New Guinea	43	1.11
Peru	28	0.72
Others	111	2.86
Total	3881	100

1.5 The Cacao Agroforestry System in Sulawesi

Agroforestry is a collective name for a land use system and technologies where woody perennials are grown deliberately on the same land as agricultural crops and/or animals. Both traditional and new approaches to agroforestry are practiced throughout tropical and subtropical developing nations (Nair, 1991).

Cacao is traditionally planted in North Sulawesi inside the forest margin. Naturally-occurring trees in the forest provide permanent shade to protect young cacao plants (the natural shade trees-cacao system). In another approach, the leguminous tree, *Glyricidia sepium* (Jacq.) Kunth ex Walp, is planted in rows as an intercrop with cacao as the main crop (the Glyricidia-cacao system). Cacao and *G. sepium* are also frequently planted with coconut trees (the coconut-glyricidia-cacao system). All of these cropping systems qualify as agroforestry and provide more diverse natural habitats than monoculture systems. In addition, they actually serve to increase the area of semi-natural 'forest' habitats in North Sulawesi. However, recently the state cacao estate in Tiniawangko has adopted a monoculture system under which sun-tolerant varieties of cacao are grown in rows with no shade or intercrop. Siebert (2002) and Belsky and Siebert

(2003) reported that traditional forest farms in central part of Sulawesi are also being converted to intensive, full-sun monocultures.

Agroforestry systems play an important role in the conservation of tropical biodiversity (Perfecto *et al.* 1996; Rice and Greenberg 2000; Philpott and Armbrecht 2006). Studies of the cacao agroforestry system, in particular, and its impact on biodiversity are limited and have dealt only with a few broad taxa (mainly, plants, ants and birds) at a few sites across the globe. In Asia and Africa such studies are few or altogether lacking (Russell-Smith 2002; Greenberg 2006). A study of the canopy fauna of tropical rainforest sites in North Sulawesi revealed that vegetation-dwelling spiders such as web-builders were most abundant (83% of all spiders) in forest canopies at the lowest altitudes (Russel-Smith and Stork 1994). Similar work in Costa Rican cloud forests supports this general finding in Sulawesi forests. Thus, it seems that lower elevation forest has more diverse and abundant spider assemblages. Yanoviac *et al.* (2003) suggest that this results from greater habitat complexity. Rice and Greenberg (2000) concluded that cacao grown closer to forest supports greater associated biological diversity.

Arthropods are excellent indicators for biodiversity because they are the most diverse component of terrestrial ecosystems (Kremen *et al.* 1993; Marshall *et al.* 1994). In addition, because of their abundance, generalist predators of herbivorous arthropods, like spiders, may have significant intrinsic functional significance for natural pest control in systems used for agricultural production (Russell 2006). Based on the information above there is a need to study the effect of different cacao habitats, ranging from the natural forest habitat to monoculture, on the diversity and abundance of spiders. Not only could the growing move to cultivation of sun-tolerant cacao monocultures have undesirable impacts on tropical biodiversity, but it could also producers in a downward spiral of increasing dependence on expensive and environmentally undesirable pest control products.

1.6 Objectives of Study

My studies as reported in this thesis, were aimed at the cacao agroforestry system in North Sulawesi, Indonesia with the main objective of documenting the diversity and abundance of spiders in different cropping systems used in cacao cultivation. The work was based on one general hypothesis, the heterogeneity hypothesis, which has been proposed to be responsible for supporting more species in complex crop habitats than in simple crop habitats.

Chapter Two examines the role of heterogeneity on diversity and abundance of spiders in different cropping systems which qualify as agroforestry systems. It attempts to establish whether this cropping system had any effect on diversity and abundance of spiders.

Chapter Three examines the impact of heterogeneity on seasonality of spiders. It provides information about the abundance of spiders in various cropping system in one season which was divided into three different time. This chapter evaluates whether the cropping system had any effect on seasonal abundance of spiders.

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Chapter 2 Diversity of ground and vegetation-dwelling spiders in cacao agroforestry systems of North Sulawesi, Indonesia

2.1 Introduction

Biodiversity refers to the number and kinds (e.g., genotypes, ecological roles) of all species of plants, animals, and microorganisms existing and interacting within an ecosystem (Altieri 1999; Gaston 1996; Collins and Qualset 1999). Changes in biodiversity may drive or be associated with undesirable changes in an ecosystem. Terrestrial arthropods are the most diverse and abundant group of multicellular animals (Marshall *et al.* 1994) and, for this reason alone, are excellent indicators of biodiversity. Surely no study of biodiversity can be considered complete without consideration of arthropods. Because we attempt to directly manage very few arthropod species, changes in their communities provide information about the unintended consequences that may result from anthropogenic activities (Spence *et al.* 1999). Species that are known to be sensitive to habitat fragmentation, pollution, or other stresses that degrade biodiversity can be used as indicator species to monitor changes in these particular aspects of managed systems (McGeoch 1998; Miyashita *et al.* 1998).

Globally, agriculture is becoming one of the main threats to biodiversity, especially in tropical countries. Increases in many pest problems have been linked to the expansion of crop monocultures (Altieri and Nicholls 2004). Monoculture systems are much less diverse than natural habitats or agroforestry systems and seem to be more vulnerable to pest activities and the associated losses (Ogol *et al.* 1999). Important ecological functions (e.g., nutrient cycling and natural pest control through environmental resistance) in these monoculture systems are replaced by expensive modern agrochemical inputs such as pesticides and fertilizers. Over the long-term this can reduce populations of natural enemies of pests, or lead to changes in an ecosystem as a whole that make growers increasingly reliant on agrochemical inputs (Gaston 1996). With increased attention to loss of biodiversity since the Rio Summit on the

environment, regional effects of agriculture on biodiversity, including natural enemy assemblages, have been subject of growing concern.

2.2 Cacao Agroforestry System in Indonesia

Cultivation of cacao in the shade of thinned primary or older secondary forest has been practiced for generations in tropical countries. In Indonesia, the alluvial soils on the coastal cacao cropping region were previously planted to other crops. Now cacao is the only crop planted there due to its high value, the rich soil and favorable rainfall patterns. Over the past two decades in Sulawesi about 50% of the new cacao cropping has appeared in formerly forested areas. Cacao was formerly cultivated in shaded systems, ranging from traditional polycultures with multiple species of planted shade trees with occasional remnant forest species to a commercial shade-tree system where other tree crops are interspersed among planted shade trees and the cacao. More recently, cultivation has moved toward a specialized shade-tree system in which one or a few tree species such as *Gliricidia sepium* (Jacq.) Steud., *Erythrina* spp., *Cassia* spp., and *Inga* spp. are planted to provide the shade. These few species provide the backbone shade component into which other fruiting and timber species may be inserted. However, it is now possible to grow varieties of cacao that do not require shade (Rice and Greenberg 2000) and thus the cacao plantations are bound to become significantly less diverse floristically.

2.3 Spider Diversity in Sulawesi

Spiders, with c. 40,000 species described worldwide, account for the highest number of described species among non-insect arthropods (Platnick 2005). The diversity of spiders has been well documented in temperate habitats, however, studies of spider species diversity in the tropics are few in number, especially for Indonesia.

Studies of the Indonesian fauna are in the early stages, with efforts devoted primarily to species and faunal description. For example, Bosmans and Hillyard (1990) reported that the forests of Sulawesi are extremely rich in spider species.

In Dumoga Bone National Park, North Sulawesi they found 11 undescribed species of the genus *Langbiana* Hogg (*Langbiana ponikii* Bosmans and Hillyard, *L. kelvini* Bosmans and Hillyard, *L. dumogabonensis* Bosmans and Hillyard, *L. hamata* Bosmans and Hillyard, *L. nigra* Bosmans and Hillyard, *L. lobata* Bosmans and Hillyard, *L. pulchra* Bosmans and Hillyard, *L. albomaculata* Bosmans and Hillyard, *L. ponikioides* Bosmans and Hillyard, *L. v-insignita* Bosmans and Hillyard, and *L. meriani* Bosmans and Hillyard) and another new species of the genus *Asceua* Thorell (*Asceua wallacei* Bosmans and Hillyard) (Araneae: Zodariidae). Bosmans (1992) also found a new *Hahnia* (*Hahnia barbata* Bosmans) and a new *Alistra* (*Alistra sulawesensis* Bosmans) (Araneae: Hahniidae). Millidge and Russell-Smith (1992) found new *Plicatiductus* (*Plicatiductus storki* Millidge and Russell-Smith), new *Dumoga* (*Dumoga arboricola* Millidge and Russell-Smith), *D. complexipalpis* Millidge and Russell-Smith, *Meinota sola* Millidge and Russell-Smith, and *Linyphia* (*Neriene*) *macella* Thorell (Araneae: Linyphiidae). Two new spiders from South Sulawesi were reported by Brignoli (1980); *Pacula sheari* Brignoli (Araneae: Pacullidae) and *Mimetus vespillo* Brignoli (Araneae: Mimetidae). Work on spiders in Sulawesi has been mainly α-level taxonomy and to date there have been no detailed reports about the diversity and abundance of spiders.

As conspicuous generalist predators (Wise 1993), spiders could contribute to natural resistance of potential pests in agricultural and agroforestry systems. In this chapter, I compared the species composition and relative abundance of spider assemblages in several agroforestry systems (specifically, the natural shade-trees cacao system the coconut-glyricidia-cacao system, and the glyricidia-cacao system) with those of the cacao monoculture system, based on samples collected with pitfall traps and sweep netting. Based on the heterogeneity hypothesis proposed by Altieri and Nicholls (1999), which states that complex crop habitats support more species than simple crop habitats, I hypothesized that the diversity and abundance of spiders in the more complex or diverse agroforestry habitats would be greater than in the simple cacao monoculture system.

Materials and Methods

Study sites

The field components of this study were conducted in North Sulawesi, Indonesia from January 2001 to May 2002. Samples were collected during two cropping seasons: 1) January 2001 to August 2001 and 2) September 2001 to May 2002. Spiders were sampled from the four different systems mainly used for production of cacao in North Sulawesi: 1) natural shade trees-cacao (NAT); 2) coconut-glyricidia-cacao (COGLY); 3) glyricidia-cacao (GLY), and 4) monoculture (MONO)(Figure 2-1). The NAT system is the traditional cultivation system, using the pre-existing variety of tropical canopy trees, as employed throughout SE Asia. The COGLY and GLY cropping systems differ only by the inclusion of coconut as an additional crop tree in the COGLY system. The MONO system is the newest cropping system that depends on use of sun-tolerant cacao.

Plot and trapping design

Although the study was originally planned to employ a balanced sampling design, full replication over the four habitats defined above, was not possible for logistical and personal safety reasons at the time of the study in North Sulawesi. Samples were distributed as follows:

1) Coconut-Glyricidia Cacao (COGLY) System (Figure 2-2): In the first year six sites were studied in the Kima area, at an altitude of 37 m a.s.l., and 13.6 Km from University of Sam Ratulangi Campus in Manado (N 01°32′, E 124°54′). In the second year 3 sites were studied in 3 different areas, one site in the Kima area, one site in the Paniki area, 10 Km from Campus (N 01°29′, E 124°54′), and one site in the Pungkol area, 35 Km from Campus (5 m a.s.l., N 01°19′, E 124°31′). Understories in the Kima and Paniki sites were diversed, ranging from leaf litter to rich in ground vegetation layers, while in the Pungkol site, understory was covered by leaf litter only.

Figure 2-1 Research sites in North Sulawesi, Indonesia. Kima (N 01°32′, E 124°54′), Paniki (N 01°29′, E 124°54′), Pungkol (N 01°19′, E 124°31′), and Tiniawangko (c. N 01°05′, E 124°23′). NAT-Natural, COGLY-Coconut-Glyricidia, GLY-Glyricidia, MONO-Monoculture.

Figure 2-2 The Coconut-Glyricidia-Cacao System (COGLY)

2) The Glyricidia-Cacao (GLY) System (Figure 2-3): In the first year three sites were studied in the Pungkol area. Understories in three sites were mainly leaf litter as cacao trees and *Glyricidia sepium* trees created shade. However, in some parts where there were open areas, understories were ground vegetation layers, mostly grasses. In the second year 3 sites were studied in 2 different areas. Two sites were located in the Pungkol area, but these can be effectively considered as different replicates as they were separated by 6 km. The first site at Pungkol was located 500 m from the COGLY site at Pungkol and the second one was 6 km away at a higher altitude and closer to both the Pungkol River and to the native forest margin. The third site, Tiniawangko, was located c. 85 Km from Campus (c. N 01°05', E 124°23'), on the east side of the main road to South Minahasa. Understories in those three sites were leaf litter in the more shaded area and ground vegetation layers in the more open area.

Figure 2-3 The Glyricidia-Cacao System (GLY)

3) The Monoculture (MONO) System (Figure 2-4): Two sites of the monoculture-cacao system were studied in the second year. Both sites were at the Tiniawangko area, c. 5 km from the Gly-Ca site. These plantings were at the lowest altitude (c. 25 m a.s.l.) for cacao plantations in Tiniawangko. The first site was on a flat landscape and the other one was located 500 m away on a steeply (45°) sloping landscape. Understory on the flat landscape was rich in ground vegetation layer, while on the steeply sloping landscapes, understory was varied, ranging from barren and leaf litter in the more shaded area to rich in ground vegetation layer in the more open area.

4) The Natural Shade Trees-Cacao (NAT) System (Figure 2-5): Only one of these sites could be located that was safe to work in and accessible in the second year. It was located at Tiniawangko, c. 2 km away from the flat MONO. Overstory that provided as permanent shade of cacao was very rich in vegetation and understory was very rich as well in ground vegetation layer.

Figure 2-4 The Monoculture-Cacao system (MONO)

Pitfall trapping, a passive collection method, was used to collect ground dwelling spiders and other arthropods. Traps consisted of plastic containers (12 cm diameter) buried in the ground with the top flush with the ground surface (Spence and Niemelä 1994). Each container was half-filled with 4% formalin solution to prevent decomposition of the soft bodied animals captured and a small amount of liquid soap to reduce surface tension. A plastic dish (25 cm diameter) was suspended on metal rods 7 cm above each trap to serve as a rain cover to minimize inadvertant capture of plant debris and reduce the evaporation of the preservative (Spence and Niemelä 1994).

In each forest or planting a grid of pitfall traps was established over an area of approximately 50 m x 50 m. Each 50 m x 50 m grid was divided into 100 quadrats, each c. 5 m x 5 m. Generally cacao trees were homogeneously distributed in the COGLY system, the GLY system, and in the MONO system. However, in the NAT system, the cacao trees were distributed more sparsely and in a more random manner. Therefore, in order to achieve the best sampling for each system, I allocated effort to 12 sample units (Figure 2-6) in a systematic sampling array (Hayek and Buzas 1997).

Figure 2-5 The Natural Shade Trees-Cacao system (NAT)

During the two sampling seasons, the contents of the pitfall traps were collected approximately every 2 weeks. Samples from pitfall traps were transferred to plastic jars at the time of collection, arthropods were subsequently removed and transferred to glass vials with 70% alcohol as preservative for storage.

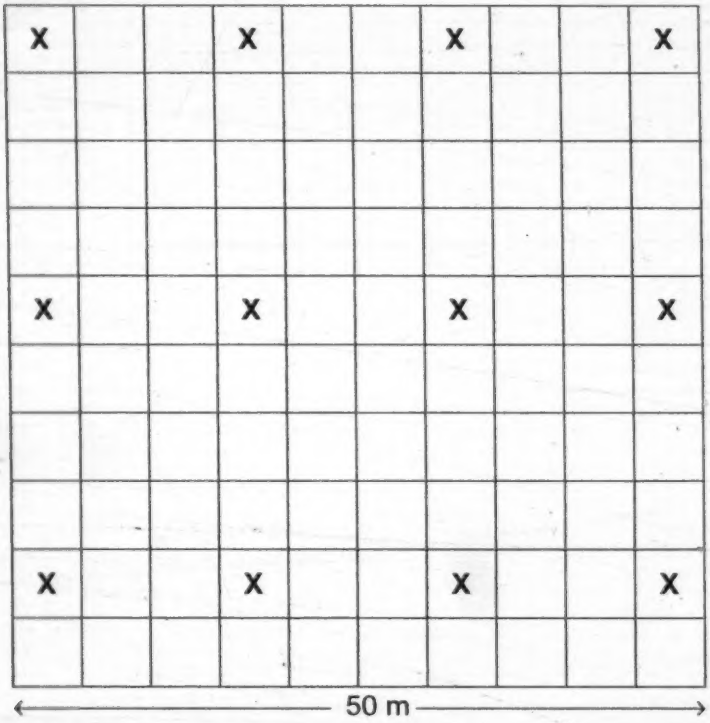

Figure 2-6 Systematic sampling in 12 quadrat units of a 2500 m^2 grid, as established in each of the nine study sites in North Sulawesi. The "X" denotes pitfall trap sampling locations.

Spiders were sampled from the vegetation using modified insect sweep nets. The sweep nets consisted of bags of very light canvas (35 cm in diameter) with 1 m long handles (Koh 1996). Two sweep nets were used to simultaneously sample spiders in every site, starting from the both edges and working towards the centre (Figure 2-7). Sweep net sampling was augmented by hand collecting; spiders observed on the ground and vegetation were collected and added to the sweep net samples. Time spent sampling ranged from 30-45 minutes depending on the evenness and slope of the landscape and the density level of the weed cover and/or cover crops. Spiders picked from the nets were stored in glass vials with 70% alcohol before sorting and identification.

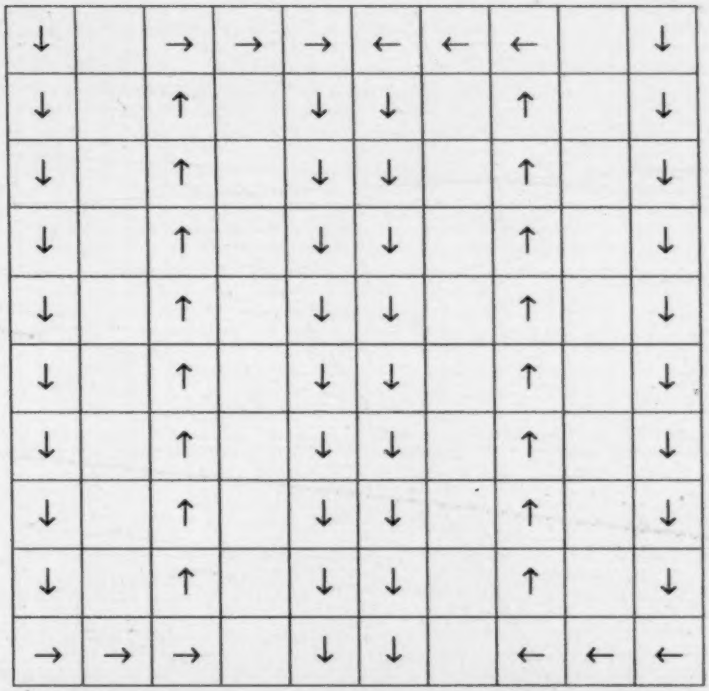

Figure 2-7 Method of sampling with sweep nets as applied on the sampling grids established at all nine field sites in North Sulawesi. Arrows indicate sweep net and hand collecting pattern.

The spiders collected were identified and classified to the lowest taxonomic level possible using the keys of Barrion and Litsinger (1995), Dippenaar-Schoeman and Jocqué (1997), Wunderlich and Song (1998), Song, *et al.* (1999), and Murphy and Murphy (2000). I collected many undescribed but easily recognizable species. These were identified as 'morphospecies' for the purposes of the analyses presented below. Voucher specimens of each of the spiders collected will be deposited at the Natural History Museum in London for further identification. The taxa were then separated into the following seven guilds based on observations about web architecture, mode of prey capture, and micro-habitat occupation or information from Barrion and Litsinger (1995) and Uetz *et al.* (1999):

1) foliage runners (Clubionidae, Heteropodidae, and Scytodidae);
2) ground runners (Lycosidae, Gnaphosidae, Oonopidae, Zodariidae, Ctenidae, Corinnidae, and Cryptothelidae);
3) stalkers/ambushers (Mimetidae, Oxyopidae, Salticidae, Thomisidae, Philodromidae, and Pisauridae);
4) sheet web-builders (Agelenidae, Amaurobiidae, Hahniidae, and Dipluridae);
5) wandering sheet/tangle weavers (Linyphiidae and Theraphosidae);
6) orb-weavers (Araneidae, Tetragnathidae, and Uloboridae); and
7) space web-builders (Theridiidae, Mysmenidae, Dictynidae, Pholcidae, and Psechridae).

Data analysis

Prior to analysis, spiders were grouped into (1) pitfall trap and (2) sweep net and hand collected captures from each cacao cropping system for each year. Capture from each trap was standardized to catch per day for each year to minimize uneven sampling effort resulting from disturbances such as animals, flooding, and human disturbance (see Niemelä *et al.* 1992). Analysis was concentrated on the second year of data when all cropping systems were sampled. However, data from the NAT system were not included in some analyses because samples from this system could not be replicated.

Species diversity was compared between treatments using rarefaction. Rarefaction allows comparisons of species richness removing the possible influence of uneven catch rates (Gotelli and Colwell 2001, Buddle *et al.* 2005, Jacobs *et al.* 2007). Calculations were performed before standardization for sampling time for each system independently, using the EstimateS 6.1 software (Colwell 2000).

Spider assemblages for pitfall trapped and sweep net collected samples were compared separately using a cluster analysis and a multi-response permutation procedure (MRPP). Cluster analysis was used to assess the degree of community similarity of spider communities for each replicate of the 3 cacao cropping systems. Community similarity among the three replicated systems

(MONO, GLY, and COGLY) were tested for significant differences using the MRPP with a Bray-Curtis distance measure. When treatment was significant, subsequent pair-wise MRPP tests were conducted to determine where those differences were (Zimmerman *et al.* 1985, Jacobs *et al.* 2007). Cluster analysis and MRPP were done using Bray-Curtis distance, and group average linking method (cluster analysis) with PCOrd 4.0 (McCune and Medford, 1999).

Abundance of 7 spider guilds was compared among three different cacao cropping systems. Abundance data were tested for homoscedasticity and normality using a Levene's test and Kolmogorov-Smirnov test respectively. When data were homoscedastic and normal, a one-factor analysis of variance (ANOVA) was used to compare abundances among the cropping systems for the various guilds (foliage runners, ground runners, stalkers/ambushers, wandering sheet/tangle weavers), when the assumptions were not met a Kruskal-Wallis test was used to compare the abundance of various guilds (sheet web-builders, orb weavers, space web builders) across the cropping systems. SPSS 14.0 (SPSS Inc. 2005) was used to perform all tests.

Results

Abundance and diversity

A total of 9787 individuals representing 294 taxa of spiders belonging to 30 families was collected from cacao agroforestry systems in North Sulawesi, Indonesia during the 2 years of the study (Table 2-1). The six most speciose families were Salticidae, Araneidae, Theridiidae, Clubionidae, Linyphiidae, and Tetragnathidae. The six most abundant families were Tetragnathidae, Araneidae, Philodromidae, Salticidae, Gnaphosidae, and Oxyopidae. Overall, Araneidae and Salticidae (52 and 51 taxa respectively) were the most diverse families collected in sweep nets and hand collecting.

Pitfall traps collected 2116 individuals representing 123 species from 24 families. Four families (Linyphiidae, Oonopidae, Theraphosidae, and

Mysmenidae) were caught only by pitfall trapping. Gnaphosidae was the most abundant, representing 22% of the total raw pitfall catch, followed by Philodromidae (21%), Linyphiidae (20%), Hahniidae (13%), Heteropodidae (12%), and Clubionidae (12%) (Table 2-1, Figure 2-8A). Linyphiidae was the most diverse family with 17 taxa, followed by Salticidae with 15 taxa collected in pitfall traps.

Sweep netting and hand collecting yielded 7671 individuals representing 223 species from 25 families. Six families (Uloboridae, Pisauridae, Scytodidae, Amaurobiidae, Dictynidae, and Psechridae) were collected only by sweeping. Tetragnathids were numerically dominant, representing 71% of the total raw catch, followed by members of Araneidae (17%), Salticidae (4%), Oxyopidae (4%), Philodromidae (3%), and Theridiidae (1%) (Table2-1, Figure 2-8B). Overall, total catch rate of vegetation-dwelling spiders was higher than ground-dwelling spiders.

Table 2-1 Spider families, abundance in pitfall traps and sweep net plus hand collecting, total abundance, number of genera and species, number of undescribed, and total richness (2001-2002) in four cacao cropping systems.

Family	Abundance			Richness			
	Pitfall	Sweep & Hand	Total	Genera	Species	Undescribed	Total
Tetragnathidae	10	5353	5363	11	7	6	17
Araneidae	17	1257	1274	27	15	27	54
Philodromidae	283	214	497	2	0	12	14
Salticidae	49	303	352	3	3	53	56
Gnaphosidae	303	4	307	1	1	8	9
Oxyopidae	1	289	290	5	4	1	6
Linyphiidae	259	0	259	3	3	14	17
Clubionidae	155	35	190	6	2	12	18
Hahniidae	166	3	169	0	0	1	1
Heteropodidae	162	1	163	1	1	0	1
Ctenidae	134	24	158	0	0	8	8
Dipluridae	139	1	140	0	0	2	2
Theridiidae	30	103	133	23	0	4	27
Lycosidae	126	3	129	2	2	9	11
Zodariidae	123	2	125	0	0	4	4
Pholcidae	73	13	86	0	0	7	7
Oonopidae	31	0	31	0	0	7	7
Corinnidae	23	2	25	0	0	2	2
Thomisidae	2	19	21	3	2	9	12
Theraphosidae	16	0	16	0	0	1	1
Cryptothelidae	6	7	13	1	1	0	1
Uloboridae	0	13	12	0	0	1	1
Mimetidae	1	10	11	0	0	6	6
Pisauridae	0	7	7	1	0	2	3
Mysmenidae	6	0	6	2	0	0	2
Scytodidae	0	5	5	1	1	2	3
Agelenidae	1	1	2	0	0	1	1
Amaurobiidae	0	1	1	0	0	1	1
Dictynidae	0	1	1	0	0	1	1
Psechridae	0	1	1	0	0	1	1

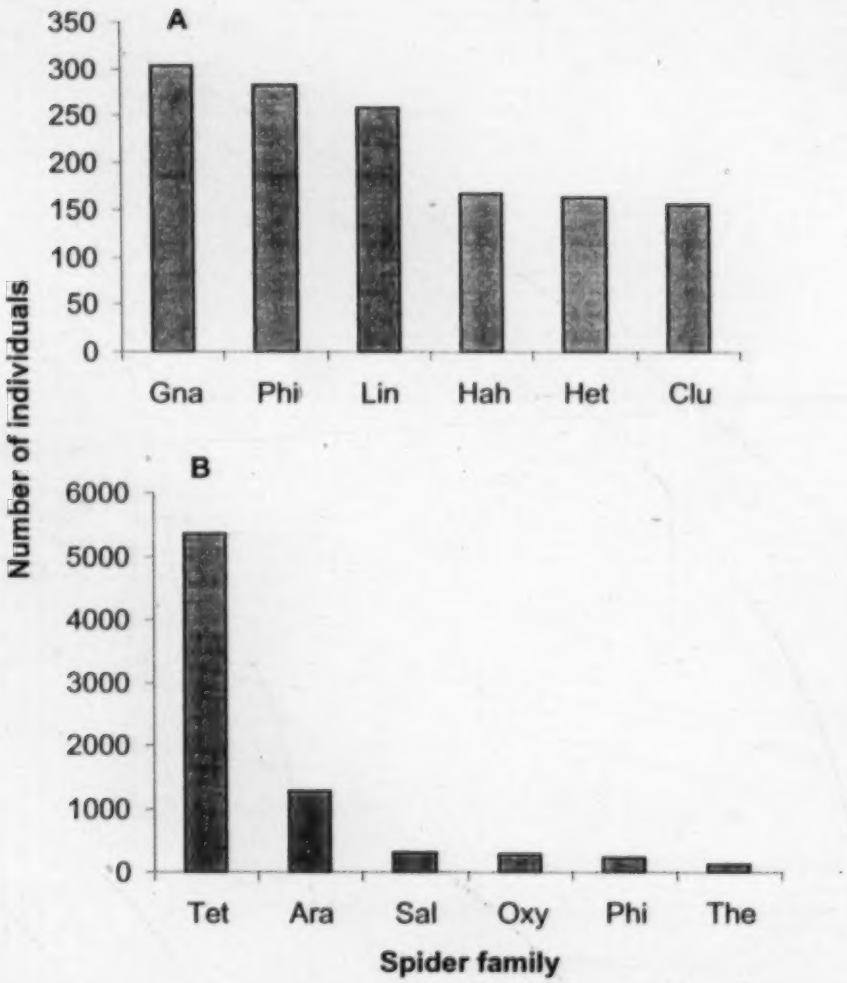

Figure 2-8 Total raw abundance of the six most abundant spider families in: (A) pitfall traps and (B) sweep nets and hand collecting. Gna-Gnaphosidae, Phi-Philodromidae, Lin- Linyphiidae, Hah-Hahniidae, Het-Heteropodidae, Clu-Clubionidae, Tet-Tetragnathidae, Ara-Araneidae, Sal-Salticidae, Oxy-Oxyopidae, The-Theridiidae.

Many spider specimens collected during the study belonged to undescribed species or, at least, could not be determined to species with available resources. Out of the 294 designated morphospecies species collected by pitfall traps and sweep netting, accurate species names could be provided for only 92 species

(Table 2-1). Furthermore, most of these species were uncommon or rarely collected. For example, of the 123 species collected by pitfall traps, 45 were represented by one individual, 15 were represented by two individuals, and 11 species were represented by three individuals. Similarly, 88 of the 223 species collected by sweeping nets plus hand collecting were represented by one individual, 42 by two individuals, and 19 by three individuals. There is no doubt that this is a hugely diverse fauna and that the sampling done in this study has only scratched the surface of the local fauna.

Spider diversity in cacao cropping systems

Rarefaction estimates of vegetation-dwelling spiders (Figure 2-9A,C), captured by sweep nets and hand collecting in the first year of the study suggest that the spider fauna of the GLY cropping system is somewhat richer in species than that of the COGLY cropping system. This trend is not apparent in data from the second year of the study, but instead the NAT had the highest species richness after controlling for sample size (c. 2100 individuals). Ground-dwelling spiders (Figure 2-9B,D), captured by pitfall traps accumulated species at similar rates in diverse crop systems (COGLY and GLY), and simple crop systems (MONO). However, the standardized abundance of six most abundant species reveals some trends among these 3 cropping systems. Web building spiders (Hahniidae sp1 and Pholcidae spA1) were most abundant in pitfall traps in MONO compared to records from both COGLY and GLY (Figure 2-10A,E). Conversely, the ground-dwelling spiders (e.g., Philodromus sp1 and Gnaphosidae sp1) were most abundant in both COGLY and GLY, but least abundant in MONO (Figure 2-10B,C).

Spider species composition between sites and habitats

Cluster analysis of spider assemblages in the 3 cropping systems indicated differences between sites and habitats. Species assemblages from the MONO I site were most similar to those from MONO II (clustering at 90% similarity for both sweep netting and hand collecting, and pitfall trap samples). The more

diverse cropping systems did not clearly cluster out together, however, they were only 35-65% similar to the MONO system, indicating that these systems support unique assemblages of both ground- and vegetation-dwelling spiders (Figure 2-11).

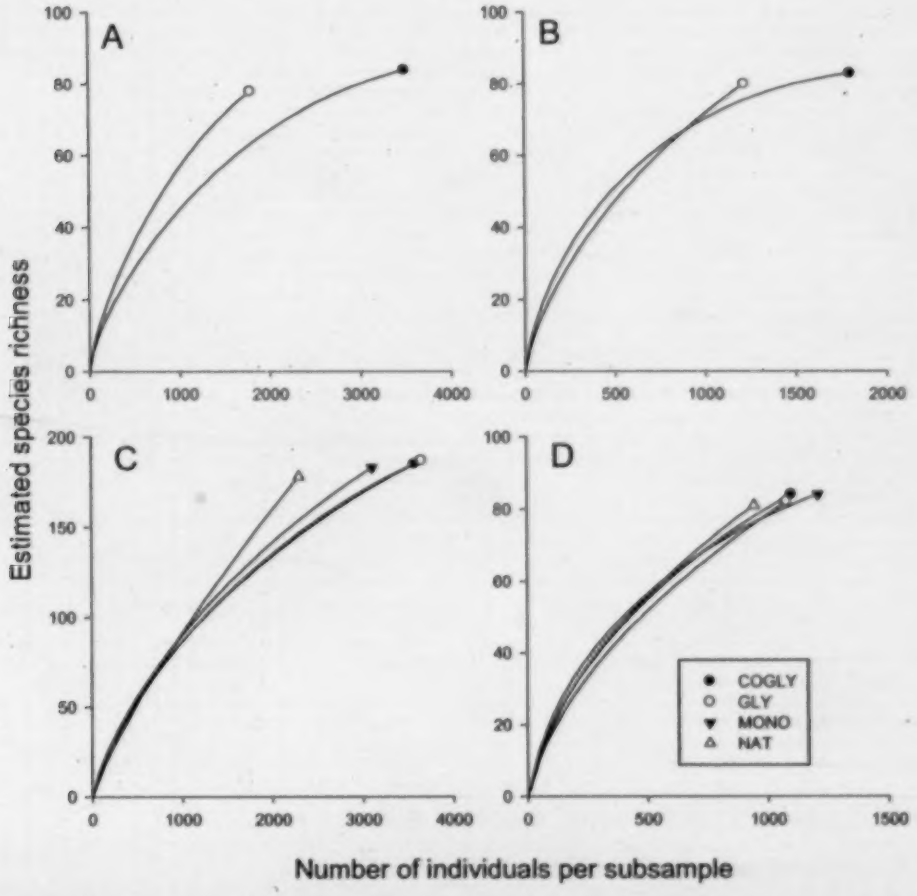

Figure 2-9 Rarefaction species curves of spiders collected by A) Sweep net and hand collecting year 1; B) pitfall traps year 1; C) sweep net and hand collecting in year 2; D) pitfall traps year 2. COGLY-Coconut-Glyricidia, Gly-Glyricidia, MONO-Monoculture, NAT-Natural.

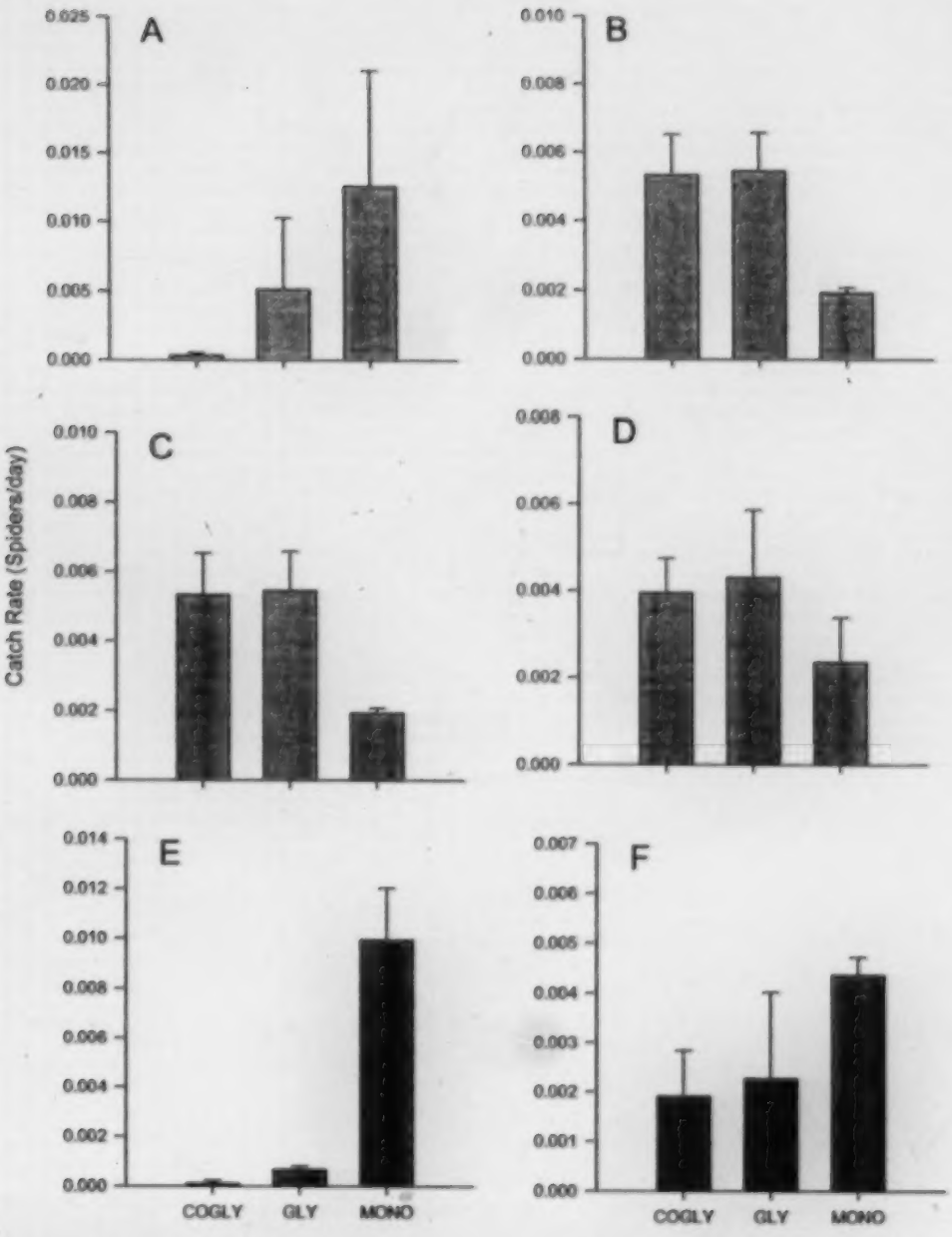

Figure 2-10 Standardized abundance of 6 most abundant spider taxa in 3 different cacao cropping systems; A)Hahniidae sp1; B)*Philodromus* sp1; C) Gnaphosidae sp1; D) *Heteropoda squamacea*; E)Pholcidae spA1 and F)Dipluridae sp1. COGLY-Coconut-Glyricidia, Gly-Glyricidia, MONO-Monoculture.

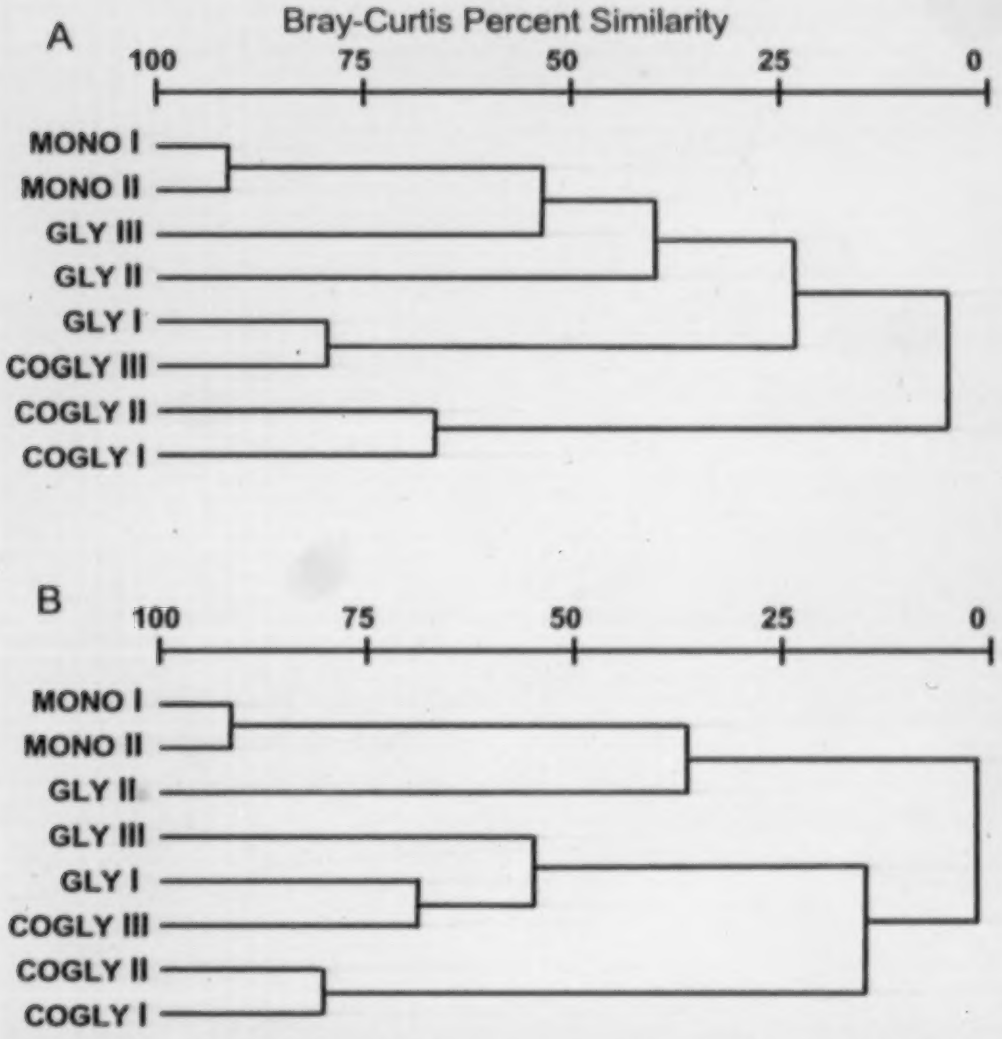

Figure 2-11 Cluster analysis of spider communities sampled by A) Sweep nets and hand collecting; and B) pitfall traps. Cluster analysis was done using Bray-Curtis distance, and group average linking method. COGLY-Coconut-Glyricidia, Gly-Glyricidia, MONO-Monoculture.

Distinction between diverse cropping systems and monoculture systems is further supported by the MRPP analysis. The MRPP of spider assemblages in the 3 cacao cropping systems (COGLY, GLY, and MONO) indicated significant differences in both vegetation types ($P = 0.029$, $A = 0.073$) and ground dwelling

(P = 0.012, A = 0.152) assemblages (Table 2-2). Pair-wise MRPP analysis demonstrated that the diverse cropping systems differed significantly from those in simple crop habitat: COGLY x MONO (P = <0.001, A = 0.093) and GLY x MONO (P = <0.001, A = 0.059) for sweep nets, and COGLY x MONO (P = <0.001, A = 0.198) and GLY x MONO (P = <0.001, A = 0.148) for pitfall traps, attesting to the significant differences among the spider assemblages collected in these various cacao cropping systems. However, it also demonstrated that spider assemblages from diverse crop habitats (COGLY & GLY) did not differ significantly from each other, nor did assemblages differ between habitats with and without coconut trees. COGLY III and GLY I are similar although the other replicates cluster at lower level of similarity because of site effect. Both of them are in the Pungkol area.

Table 2-2 Multiresponse permutation procedure (MRPP) for spiders collected by sweep nets and pitfall traps (A=chance-corrected within group agreement "effect size", P=probability that an observed difference is due to chance).

	A	P
Sweep nets	0.073	0.029*
COGLY x GLY	0.036	0.143
COGLY x MONO	0.093	<0.001*
GLY x MONO	0.059	<0.001*
Pitfall traps	0.152	0.012*
COGLY x GLY	0.060	0.080
COGLY x MONO	0.198	<0.001*
GLY x MONO	0.148	<0.001*

Spider guild composition in cacao cropping systems

Overall, the simplest crop habitat (MONO) had the highest catch rate of spiders (0.07 spider/day) compared to diverse crop habitats, COGLY (0.04 spider/day) and GLY (0.03 spider/day) (Figure 2-12). When catch rate of spiders were grouped into guilds, ground runners were the only guild that showed a significant difference among cropping systems (P=0.028). The ground runners were significantly more abundant in the MONO than the more diverse cropping

systems (P<0.05) (Figure 2-13C, Table 2-3). Although the differences were of only marginal significance, web-builders were more abundant in MONO compared to COGLY and GLY (P=0.093).

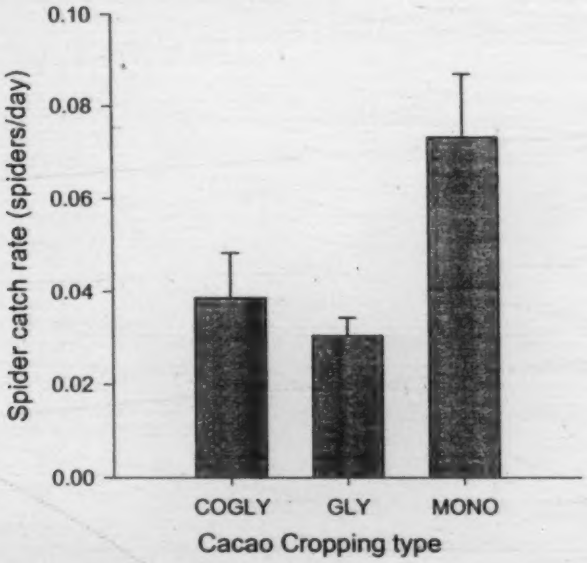

Figure 2-12 Total Standardized spider abundance in year 2. COGLY-Coconut-Glyricidia, Gly-Glyricidia, MONO-Monoculture.

Table 2-3 Results of ANOVA (foliage runners,ground runners, stalkers/ ambushers, and sheet web-builders) and Kruskal-Wallis (wandering sheet/tangle weavers, orb-weavers, and space web-builders) tests comparing standardized abundance of 7 spider guilds among three cacao cropping systems. (MONO-Monoculture;COGLY-Coconut-Glyricidia; GLY-Glyricidia)

Spider Guild	Test	F/K-W Statistic	P	LSD
Foliage Runners	ANOVA	0.9	0.46	-
Ground runners	ANOVA	7.9	0.02*	MONO>COGLY, GLY
Stalkers/ambushers	ANOVA	1.5	0.30	-
Sheet web-builders	K-W	3.2	0.20	-
Wandering sheet/tangle weavers	ANOVA	1.9	0.24	-
Orb weavers	K-W	0.6	0.73	-
Space web builders	K-W	4.8	0.09	-

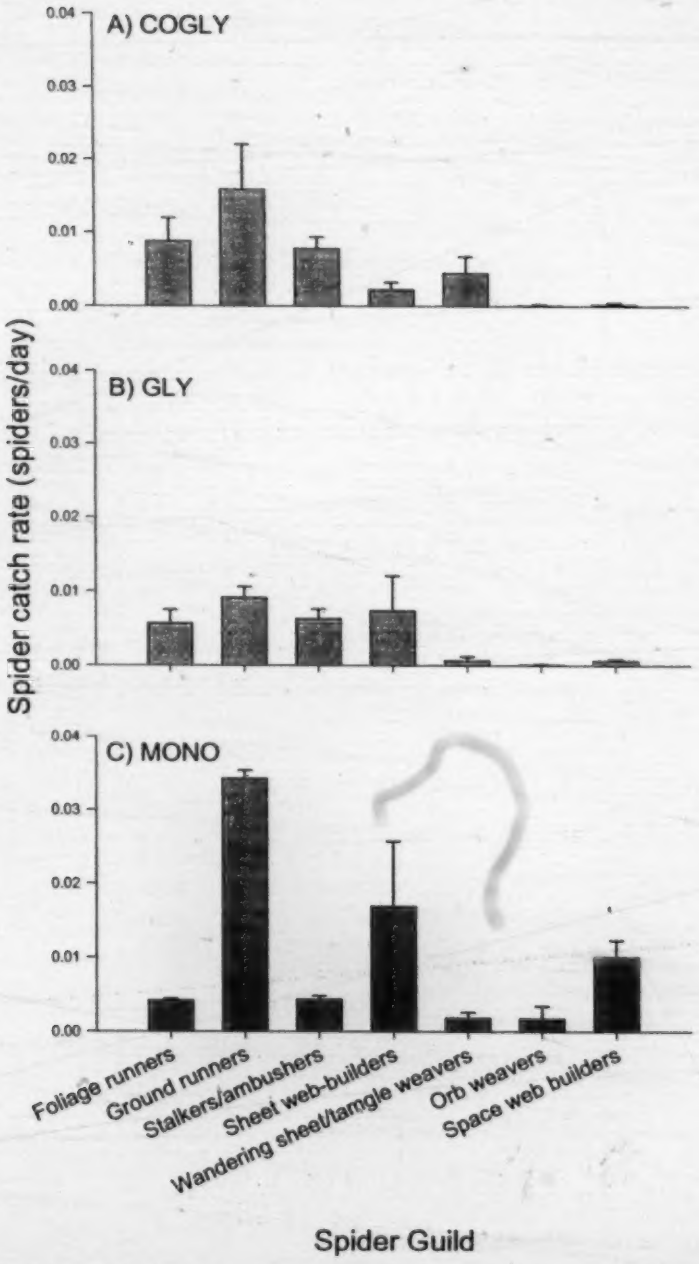

Figure 2-13 Spider guilds abundance in three cacao cropping systems. COGLY-Coconut- Glyricidia, Gly-Glyricidia, MONO-Monoculture.

Discussion

Clearly, use of agroforestry systems for cacao cultivation contributes positively to conservation of tropical biodiversity in North Sulawesi, Indonesia. Shaded cacao plantations can suport a local species diversity within the same order of magnitude as undisturbed forest (Perfecto *et al.* 1996; Rice and Greenberg 2000; Philpott and Armbrecht 2006). The present study emphasizes the importance of diverse crop habitats on spider abundance, species diversity and guild composition.

The influence of cropping system on species diversity

Andow (1991) and Altieri (1999) concluded that more diverse crop habitats support more species due to greater habitat complexity that provides more microhabitats for exploitation by arthropods. Andow (1991) hypothesized that greater biodiversity in a community of organisms is associated with greater stability of that community. The simple crop monoculture system, for example, is less diverse than natural or diversified crop habitats and important ecological functions are lost due to biological simplification. Simplified monoculture habitats generally requires constant human intervention (i.e. modern agriculture practices) for predictable yields (Altieri and Nicholls 2004).

My prediction that greater spider diversity and abundance would be found in diverse habitats than in simple crop habitats was supported in the second year of study. The NAT cropping system had the highest species richness of vegetation-dwelling spiders, after controlling for sample size (c. 2100 individuals) (Figure 2-10C). However, I did not find a similar trend for ground-dwelling spiders as there was no difference in species richness between diverse and simple crop habitats (Figure 2-10D).

Standardized data indicated that the six most abundant spider taxa in pitfall traps responded differently to the range of habitats studied. *Philodromus* sp1 and Gnaphosidae sp1 were most abundant in diverse crop habitats (COGLY and GLY) compared to simple crop habitat, MONO (Figure 2-11B,C). Dippenaar-Schoeman and Jocqué (1997) and Murphy and Murphy (2000) argued that free-

living hunting spiders, such as philodromids, are commonly found on shrubs, plants, in litter, or on the soil surface but that other spiders, like most gnaphosids, are ground-dwellers with only a few living on plants. Therefore, free-living hunting spiders, are commonly found in each habitat. The greater habitat complexity of diverse crop habitats is associated with higher abundance in many cropping systems (Andow 1991; Perfecto *et al.* 1996; Rypstra *et al.* 1999; Yanoviac *et al.* 2003; Altieri and Nicholls 2004).

Hahniidae sp1 and Pholcidae sp1 are small (≤ 2-10 mm) web-builders, however, they are active at the ground level only (Dippenaar-Schoeman and Jocqué 1997; Murphy and Murphy 2000). These two taxa were most abundant in simple crop habitat and least abundant in diverse crop habitats (Figure 2-11A,E). Changes in habitat structure from the natural habitat to simplified (MONO) system affect spider species abundance and diversity. Hahniidae sp1 and Pholcidae sp1 were present in the MONO system, indicating that both species were well adapted in the most disturbed habitat. Alaruika *et al.* (2002) observed no significant changes in spider abundance or species richness (captured by pitfall traps) across a Finnish urban-rural gradient in relation to habitat specialization. However, individual species responded differently to urbanization. Clearly, highly disturbed habitats, such as provided by monoculture and urbanized areas, have significant effects on spider diversity.

The influence of cropping system on species composition

Traditional agriculture practices that enhance the structural complexity of the environment such as is accomplished by intercropping, mulching, and tillage conservation also enhance the density and diversity of spider communities (Rypstra *et al.* 1999). Many authors (e.g., Buddle *et al.* 2003, Schmidt *et al.* 2005, Clough *et al.* 2005, and Isaia *et al.* 2006) have concluded that the structure of agricultural landscapes affects the diversity of spiders. Similarly, Langellotto and Denno (2004) showed that spider assemblages were negatively affected when habitat structure was simplified. Rypstra *et al.* (1999) summarized evidence to generalize that ground-dwelling spiders increase in abundance when

the litter layer is enhanced by addition of retreats and hiding places and the range of temperature and humidity is moderate. Abundance of vegetation-dwelling spiders such as web builders is positively correlated with the availability of web attachment sites (Rypstra *et al.* 1999).

Results of this study demonstrate that cacao agroforestry systems used in North Sulawesi also affect the species composition of spider assemblages. Somewhat unexpectedly, the species composition of more diverse cropping systems did not cluster out together; however, assemblages from these systems were only 35-65 % similar to those from the simple crop systems (Figure 2-12). Furthermore, differences between diversified cropping systems and monoculture systems were highly significant (Table 2-2), indicating that these various systems support unique assemblages of both ground and vegetation dwelling spiders. Movement to the single approach of cultivating sun tolerant cacao in monocultures will certainly be coupled to a loss in biodiversity of spiders on the land base devoted to this crop in North Indonesia.

The significant differences between spider assemblages of these farming systems may reflect variation in canopy cover, local microclimates, and specific vegetation structures that support web attachment. The open canopy of the sun tolerant monoculture cacao systems permits growth of more diverse ground vegetation, thus perhaps supporting a higher abundance of ground-running spiders. In the diverse cropping systems or shade-cacao systems, shade from the overstory trees suppresses the ground vegetation layers, thus suppresses ground-running spiders. Even though the diverse cropping systems received only low level disturbance, the ground-running assemblage as sampled by pitfall trapping was not significantly richer than that found in the much more highly disturbed MONO systems. However, presence of refuge areas in more diverse cropping systems may reduce the capture rate of pitfall traps, thereby reducing estimates of relative abundance.

The influence of cropping system on guild composition

Spider guild composition responds to vegetation diversity and structural complexity (Uetz *et al.* 1999; Rypstra *et al.* 1999; McNett and Rypstra 2000). For example, Chen and Tso (2004) and Tsai *et al.* (2006) showed that spider guild composition varied significantly among four forest types in Orchid Island, Taiwan.

Results of the present study demonstrate that variation in the structure of cacao cropping systems in North Sulawesi also affects spider guild composition. Guild composition differed among the COGLY, GLY, and MONO systems, however, all assemblages were dominated by ground runners. Composition of the ground runner guild was significantly influenced by vegetation diversity and structural complexity. Ground running species were more abundant in the MONO system than in the more diverse cropping systems (Figure 2-13C, Table 2-3). Although the difference was not significant given the relatively low level of replication, space web-builders also tended to be more abundant in the MONO system compared to more diverse crop habitats (Figure 2-13C). This finding suggests that in sun-tolerant cacao systems, there is no canopy cover and/or more open areas. Since the abundance of spiders is markedly influenced by vegetation diversity and structure, an open area allows the ground vegetation layer to grow densely, generating more retreats and hiding places, and moderating temperature and humidity extremes (Rypstra *et al.* 1999; Chen and Tso 2004; Tsai *et al.* 2006). As a result of such increases in acceptable habitat, I suggest that populations of ground spiders and ground active web builders are able to expand in the MONO system relative to the more diverse systems. Thus, the significant difference in spider guild composition between the MONO system and the more diverse cropping systems probably reflects variation in structural, local microclimatic, and microhabitat occupancy.

Implications for cacao agroforestry management

The importance of maintaining vegetational diversity in protecting arthropod biodiversity is well understood globally and the implications have led to modified

agricultural practice in Latin and Central America, Mexico, Columbia, West Africa, and Southeast Asia. Traditional systems such as shaded cacao and coffee agroforestry are highlighted for their ability to provide biodiversity refuges. Diversity increased with increases in both floristic and structural diversity of vegetation growing in the shade of cacao. On the other hand, 'modern' production-oriented systems such as sun-tolerant monoculture cropping systems of cacao negatively affect arthropod diversity (Perfecto *et al.* 1996; Rice and Greenberg 2000; Siebert 2002; Klein *et al.* 2002; Greenberg 2006; Philpott and Armbrecht 2006; Philpott *et al.* 2006;).

It is clear that traditional systems such as cacao agroforestry affect abundance and species diversity, species and guild compositions of spider assemblages. Based on the present results, shaded cacao systems such as the NAT, the COGLY, and the GLY systems should be maintained for conservation of overall biodiversity in North Sulawesi. In particular, the use of shade plant such as *Gliricidia sepium* (Jacq.) Steud. should be continued in tropical cacao fields. This shade plant species can be inserted with other economically important plants as the 'backbone' of a strategy for both enhancing diversity and supporting cacao farmers financially. Although the forgoing data suggest that standardized abundance of ground-dwelling spiders was higher in the MONO system compared to cacao agroforestry systems there are complications in the interpretation. First, although spider abundance was lower in the sites with significant overstory, the composition of the assemblages differed considerably from that in the MONO systems. In addition, the state cacao estate in Tiniawangko did not practice weed control on a regular basis because of high maintenance cost. This might be a reason why populations of ground dwelling spiders seemed to be higher in the MONO systems employed on the estate. Given that such increases were associated with an enhanced diversity of the ground vegetation layer, introducing ground cover crops, such as peanuts or yams, could prevent the growth of unwanted plants such as weeds and also provide refuges for generalist predators like spiders.

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Chapter 3 Seasonality in tropical spider assemblages

Introduction

It is important to consider potential influences of temporal factors on arthropod communities when using indicator species to monitor disturbances resulting from different land use practices. Just as understanding spatial patterns can help us discern associations between organisms and recurrent habitat conditions, recurrent temporal patterns, often rooted in seasonally-based events, can help identify causes for population and community change. Seasonality is driven by patterns of weather change during a year. Seasonal effects may result in presence or absence of a set of species at particular points in time, as well as fluctuations in relative abundance of permanently occurring species (Norris 1999; Relys *et al.* 2002).

In most tropical regions dry and wet seasons are more or less pronounced (Nentwig 1989). Like other regions of Indonesia, North Sulawesi province has a typical equatorial climate characterized by significant differences in rainfall. Cool Northwesternly winds that have picked up moisture while crossing the South China Sea arrive in the Sulawesi Sea during November. The main rainy season lasts approximately from November to March, but it is generally less pronounced than in many other parts of SE Asia. Thunderstorms are common during the rainy season.

Spider assemblages are good indicators of habitat alteration, particularly for monitoring changes due to disturbance or temporal factors (Uetz 1979; Uetz 1991; Ward and Lubin 1992; Wise 1993; Niemelä *et al.* 1994; Polis *et al.* 1998; Arango *et al.* 2000; McNett and Rypstra 2000; Gasnier and Höfer 2001; Gasnier *et al.* 2002; Romero and Vasconcellos-Neto 2003; Jiménez-Valverde and Lobo 2007). Changes in spider assemblages can reflect ecological impacts at lower levels in the food web (Churchill 1997).

Several studies have emphasized that time of sampling was an important consideration in monitoring differences in spider species composition (Whitmore *et al.* 2002, Niemelä *et al.* 1994, Norris 1999). Niemelä *et al.* (1994), for example,

found seasonal differences in peak abundance for common forest floor spider assemblages. McNett and Rypstra (2000) found that residence time was related to disturbance and habitat destruction. There are many factors that may affect peak activity/abundance patterns of tropical spiders: 1) rainfall (Tanaka and Tanaka 1982; Niemelä *et al.* 1994; Langlands *et al.* 2006); 2) dry and wet seasons (Lubin 1978; Pearson and Derr 1985; Burgess *et al.* 1999; Romero and Vasconcellos-Neto 2003); 3) habitat selection (Abraham 1983; McNett and Rypstra 2000; Weeks and Holtzer 2000; Jõgar *et al.* 2004); 4) fire (Langlands *et al.* 2006); 5) migration (Kraus and Morse 2005); 6) life cycle (Arango *et al.* 2000); and 7) resource availability (Ward and Lubin 1992; Polis *et al.* 1998; Arango *et al.* 2000; Bonte and Mertens 2003).

Studies of seasonality in spider assemblages have been conducted widely in North America, Europe, Australia, and the Far East in various habitats such as in a desert (Gertsch and Riechert 1976), islands (Polis *et al.* 1998; LaSalle and De La Cruz 1985), the Mediterranean (Jiménez-Valverde and Lobo 2006; Jiménez-Valverde and Lobo 2007), arid (Langlands *et al.* 2006), heathland (Churchill and Arthur 1999), grassland (Arrango *et al.* 2000; Varol and Kutbay 2005; Romero and Vasconcellos-Neto 2005), coastal (Tanaka and Tanaka 1982; Ward and Lubin 1992), boreal forest (Niemelä *et al.* 1994), and tropical forest (Lubin 1978; Nentwig 1989; Frith and Frith 1990; Romero and Vasconcellos-Neto 2003; Romero and Vasconcellos-Neto 2005). However, there has been little study of temporal factors influencing tropical spider assemblages and virtually nothing is known about this matter with reference to spiders of Sulawesi, Indonesia. Because of the close association of spiders with habitat structure, spider communities and individual species will have clear seasonal patterns.

Materials and methods

Study area

The study was carried out in the province of North Sulawesi, Indonesia which is located at 0°30′ – 4°3′ North Latitude and 121°127′ East Longitude. Samples were collected from September 2001 to May 2002 and divided into 3 seasons for

analysis: 1) early season (September-November 2001); 2) mid season (December 2001-February 2002), and 3) late season (March-May 2002). Rainfall data were recorded from three weather stations representative of the four study areas: 1) Kayuwatu, the closest recording station for the Kima and Paniki areas; 2) Pungkol station for the Pungkol area, and 3) Tenga, the closest recording station for the Tiniawangko area.

Site descriptions

Samples were collected in Kima (N 01°32′, E 124°54′), Paniki (N 01°29′, E 124°54′), Pungkol (N 01°19′, E 124°31′), and Tiniawangko (c. N 01°05′, E 124°23′). Spiders were sampled as follows in four different cacao-cropping systems: 1) natural shade trees-cacao (NAT); 2) cacao grown under a coconut, glyricidia canopy (COGLY); 3) cacao grown under just a glyricidia canopy (GLY), and 4) a monoculture cacao field (MONO) (See Chapter 2 for a more complete explanation of these systems). Spatial distribution of the sites and replication of the cropping systems was dictated by access and availability as follows:

1) Kima. One site/ replicate of the COGLY system (COGLY I).
2) Paniki. One site/replicate of the COGLY system (COGLY II).
3) Pungkol. Three sites were studied in this area; one site/replicate of the COGLY system (COGLY III), and two sites/replicates of the GLY system (GLY I and GLY II).
4) Tiniawangko. Four sites were studied in this area; one site/replicate of the GLY system (GLY III), two sites/replicates of the MONO system (MONO I and MONO II), and one site/replicate of the NAT system.

Sampling protocol

Spiders were sampled using pitfall traps. Pitfall traps each comprised a 12 cm diameter plastic containers inserted into the ground so that the lip was flush with the soil surface (Spence and Niemelä 1994). Each trap was half-filled with 4% formalin solution, as a preserving agent, and a few drops of detergent to break

the surface tension. A 25 cm diameter plastic dish was suspended on metal rods 7 cm above each trap to protect the trap from rain as well as to minimize capture of plant debris and reduce evaporation of the preservative (Spence and Niemelä 1994).

A grid of pitfall traps was arranged at each site covering an area of approximately 50 m x 50 m. Each 50 m x 50 m grid was divided into 100 quadrats, each 5 m x 5 m. Twelve pitfall traps were allocated to the grid in a systematic sampling regime (Figure 3-1) (Hayek and Buzas 1997). In total there were 108 pitfall traps at the nine study sites. The contents of the pitfall traps were collected approximately every 2 weeks. Samples were transferred to plastic jars at the time of collection and arthropods were subsequently removed and transferred to glass vials with 70% alcohol as preservative for storage until they could be sorted and identified.

The spiders collected were identified and classified to the lowest taxonomic level possible using the keys of Barrion and Litsinger (1995), Dippenaar-Schoeman and Jocqué (1997), Wunderlich and Song (1998), Song, *et al.* (1999), and Murphy and Murphy (2000). Spiders were identified to species when possible, but given the poor existing knowledge of the Indonesian spider fauna, many taxa were identified as morphospecies. Voucher specimens of each of the spiders collected will be deposited at the Natural History Museum in London for further identification.

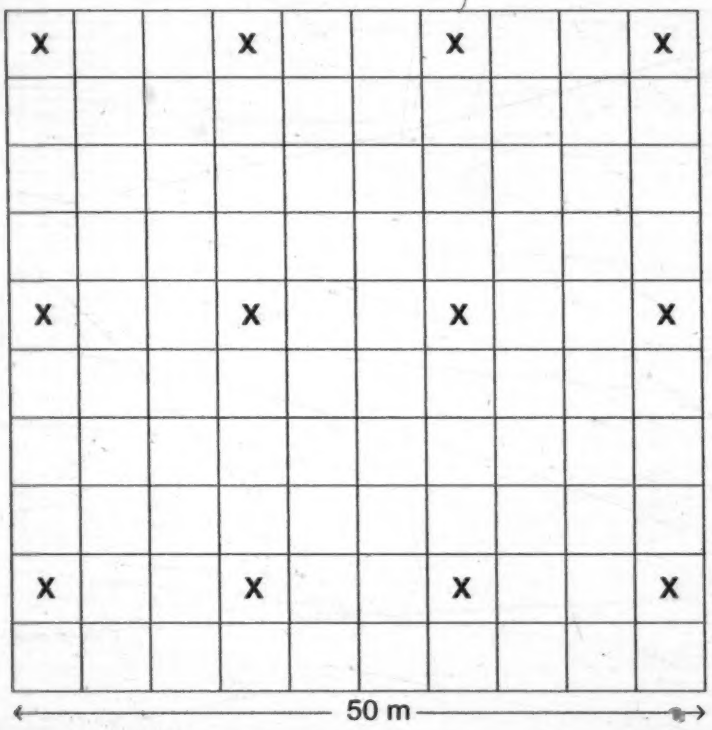

Figure 3-1 Systematic sampling in 12 quadrat units of a 2500 m2 grid, as established in each of the nine study sites in North Sulawesi. The "X" denotes pitfall trap sampling locations.

Statistical analysis

Captures from each trap were standardized to catch per day to minimize uneven sampling effort resulting from disturbances such as animals, flooding, and human disturbance (see Niemelä et al. 1992).

A one-factor analysis of variance (ANOVA) was used to investigate seasonal patterns. Samples were divided into 3 seasons: 1) early season (September-November 2001); 2) mid season (December 2001-February 2002), and 3) late season (March-May 2002). Rainfall was compared between the three rainfall stations, and total spider abundance and the abundance of the species representing greater than 10% of the total relative abundance were compared across the 8 research fields (2 sites in MONO, 3 sites each in of GLY and

COGLY). When significant main effects were detected, Tukey's Post-hoc test was used for pair-wise comparisons.

A 2-factor ANOVA was used to investigate cropping systems, seasonality and the interaction between them for total spider abundance. A 2-factor MANOVA was used to look at possible interaction between cropping system and seasonality in species representing greater than 10% of the total relative abundance were compared between 4 cropping systems and 3 seasons (early, mid, and late). Pillai's Trace test was used to detect main effects in the MANOVA. All ANOVA analyses were performed using SPSS 14.0 (SPSS Inc. 2005).

Results

Rainfall

Mean daily rainfall among the 3 weather stations that surround the sites varied significantly (ANOVA: $F=5.85$, $P=0.005$). Tukey's post hoc test revealed mid season (December-February) had a significantly higher mean daily rainfall (13.6 mm/day) than either the early season (September–November) (7.7 mm/day) or the late season (March–May) (5.4 mm/day) (Figure 3-2). Thus, the sites had a seasonal peak in rainfall during the middle of my sampling year.

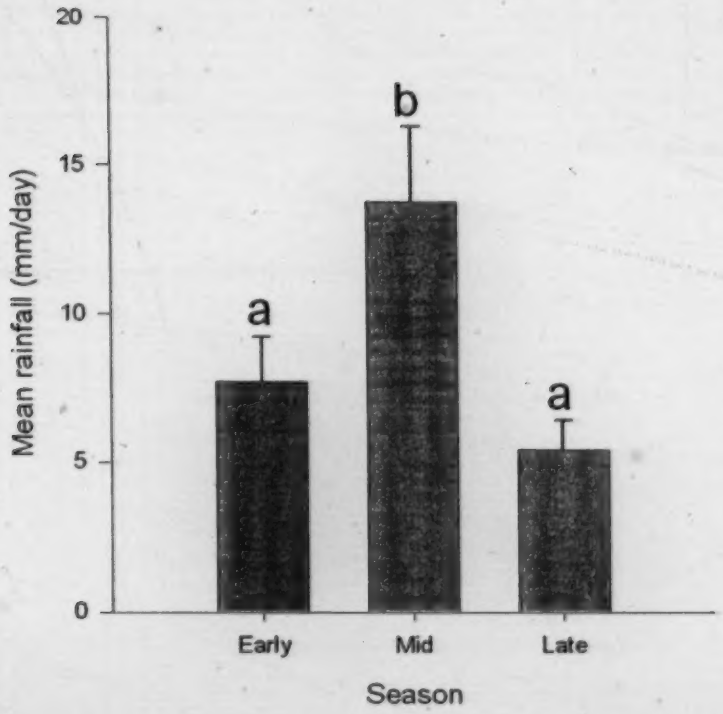

Figure 3-2 Mean daily rainfall (mm) across sites. Letters denote significant difference of Tukey's post-hoc test. (Early: Sept-Nov; Mid: Dec-Feb; Late: March-May)

Seasonal patterns of spider abundance and species

Data about abundance of species that represented at least 10% of the total relative abundance were analysed to investigate seasonal patterns with one factor ANOVA. Samples were divided into 3 seasons, as above.

Overall spider catch varied significantly across the three seasons used for this analysis (ANOVA, $F=8.51$, $P<0.001$). Spider catch was significantly higher during the early season than in either the mid or late seasons (Figure 3-3). These assemblages appear to have a seasonal pattern, with higher abundance preceeding the rainy season and reduced abundance during and following the rainy season.

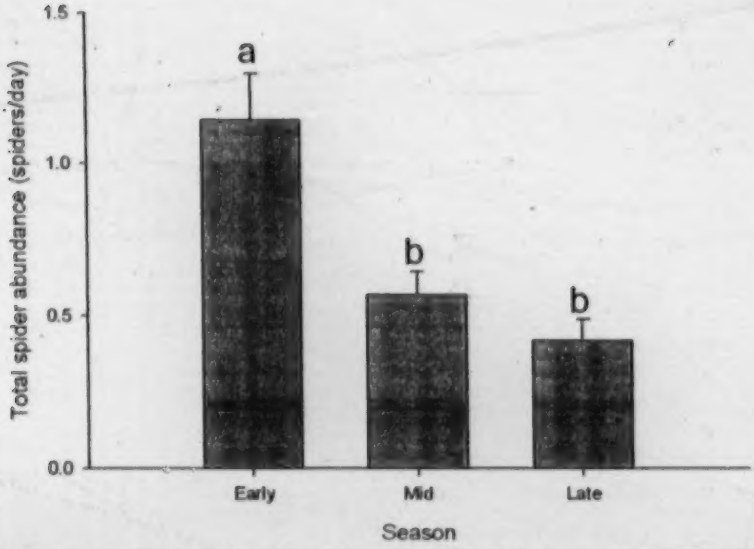

Figure 3-3 Mean total standardized spider abundance in each season. Letters denote significant differences fromTukey's post-hoc test.

Four of the 22 species representing greater than 10% relative abundance, showed significant changes in abundance across seasons. Those four species showing evident seasonality all peaked in abundance in the early season, prior to peak rainfall (Figure 3-4).

Temporal activity of the 4 most abundance species indicated their specific response to seasonality. Hahniidae, Pholcidae, and Linyphiidae are small, web building spiders, however they are mostly active on the ground (Barrion and Litsinger 1995; Dippenaar-Schoeman and Jocqué 1997; Murphy and Murphy (2000). Gnaphosidae are ground-dwelling spiders and are ground runners (Uetz *et al.* 1999).

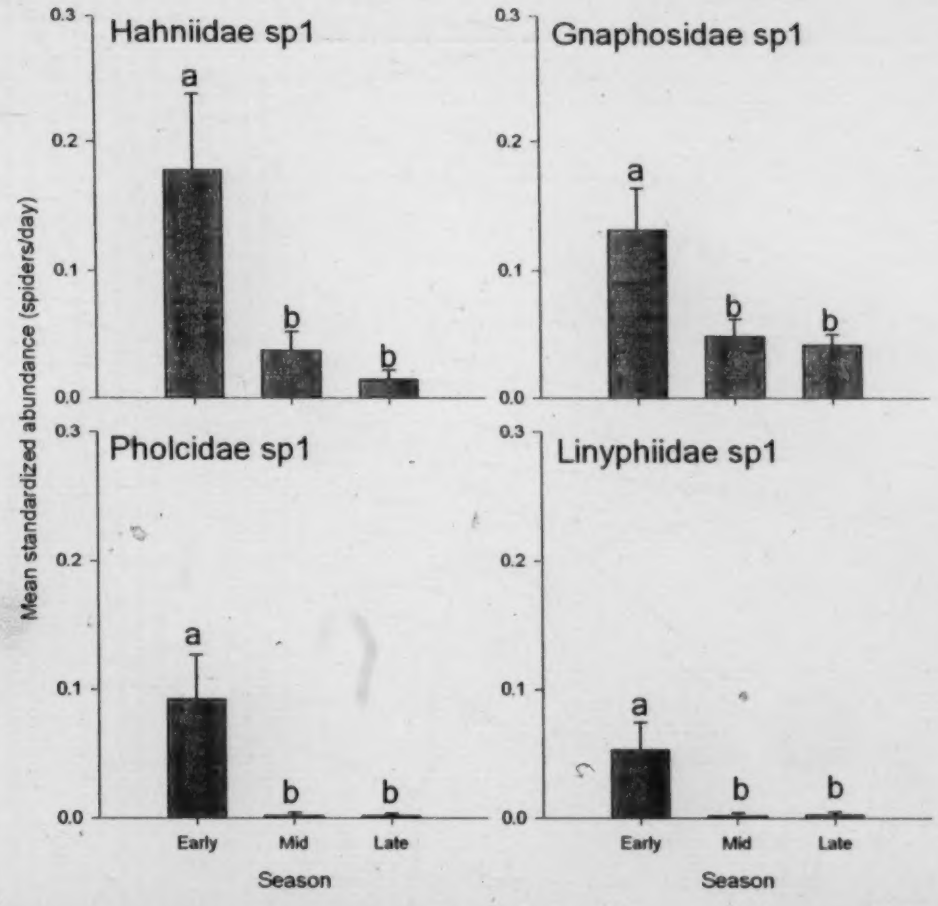

Figure 3-4 Mean standardized abundance of the 4 most abundant spiders with showing significant differences between seasons. Letters denote significant differences fromTukey's post-hoc test.

Seasonal patterns of spider abundance and species in each cropping system

Overall spider abundance was compared between 3 cropping systems (MONO, GLY, and GLYCA among 3 seasons: 1) early season (September-November 2001); 2) mid season (December 2001-February 2002), and 3) late season (March-May 2002) using a 2 factor ANOVA. Data about the NAT system were used for graphical comparison but are not included in the analysis because samples from this system could not be replicated.

Results of the ANOVA revealed a significant effect of cropping system (ANOVA, $F=4.72$, $P=0.03$) and season (ANOVA, $F=14.49$, $P<0.001$) on spider abundance. Seasonal abundance patterns of spiders in the simplified habitat (MONO) and semi natural habitat (GLY) systems, showed an initial declining trend before reaching a high peak in the early rainy season and then reduced abundance during and following the rainy season. Spiders in the semi natural habitat (COGLY) system were characterized by somewhat different seasonal patterns in abundance, being more abundant in the early rainy season, reduced abundance during the rainy season, and increased abundance following the rainy season (Figure 3-5). Seasonal abundance patterns of spiders in the NAT system appeared to be very different from those in the MONO, GLY, and COGLY systems, with spiders reaching the peak abuncance in the mid season (where in other cropping systems their abundance decreased during rainy season), and reduced abundance in the early and following the rainy season.

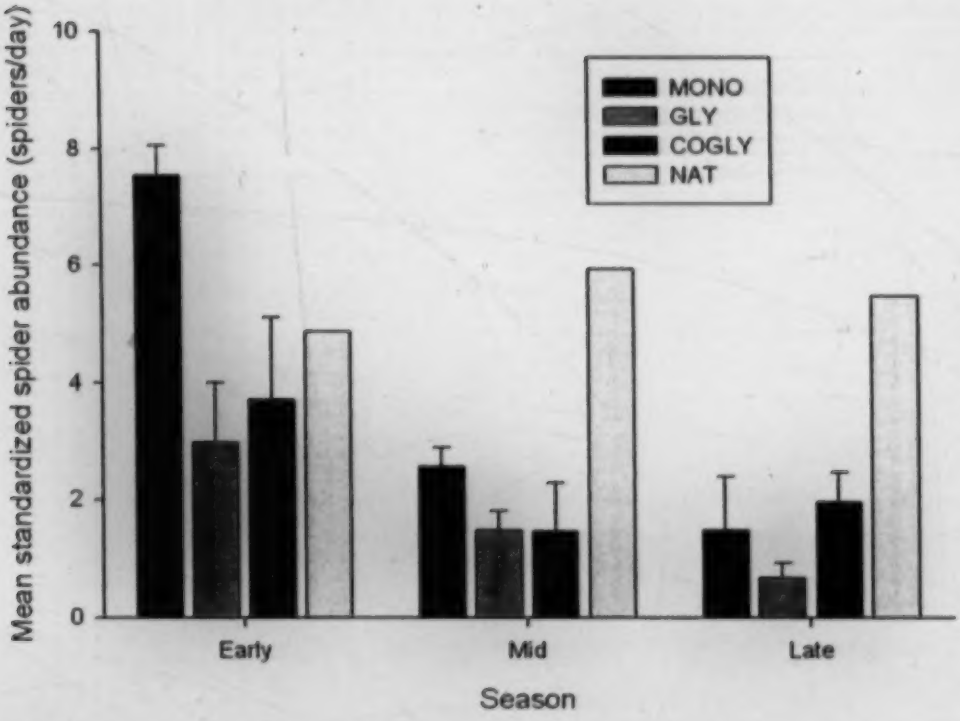

Figure 3-5 Mean standardized abundance of spiders in each season. MONO-Monoculture, GLY-Glyricidia, COGLY-Coconut-Glyricidia, NAT-Natural.

Spider species were compared between cropping systems and seasons using a 2-factor MANOVA. Pillai's Trace test was used to test differences in relative abundance of spiders between system and season.

Results of MANOVA demonstrated there is a significant difference in spider abundance between seasons ($F=17.7$, $P=0.01$) and between systems ($F=5.6$, $P=0.05$), but no interaction between both of them ($F=2.0$, $P=0.07$)(Table 3-1). However, Pholcidae sp A1 ($F=71.19$, $P=<0.001$) and Ctenidae sp5 ($F=12.28$, $P=<0.001$) showed significant interaction in species abundance between season and system.

Interaction of season and system in species abundance indicate that cropping systems affect seasonality differently in the spiders that I studied. In the simplified (MONO) system, space web-builder Pholcidae spA1 followed a similar

trend to spider seasonal abundance patterns, reaching the high peak in the early rainy season, and reduced abundance during and following the rainy season. In the semi natural habitat (GLY) and natural habitat (NAT) systems, Pholcidae spA1 were only present in the early rainy season. No individuals were present in the COGLY system (Figure 3-6). The nocturnal wandering spider Ctenidae sp5 also showed different seasonal abundance patterns across crops. In the MONO system, this species reached high abundance during the rainy season and presented reduced abundance in the early and late rainy seasons. In the natural habitat (NAT) system, however, seasonal abundance patterns did not obviously vary with season. In the GLY system, Ctenidae sp5 were absent in the early rainy season, but were found in very low abundance during and following the rainy season. No individuals of Ctenidae sp5 were present in the semi natural (COGLY) system (Figure 3-6).

Table 3-1 Multivariate ANOVA for spider abundance differences between season and system using Pillai's Trace test.

Effect	F	Error df	P
Season	17.7[a]	4	0.01
System	5.6	4	0.05
Season x System	2.0	16	0.07

a. Exact statistic

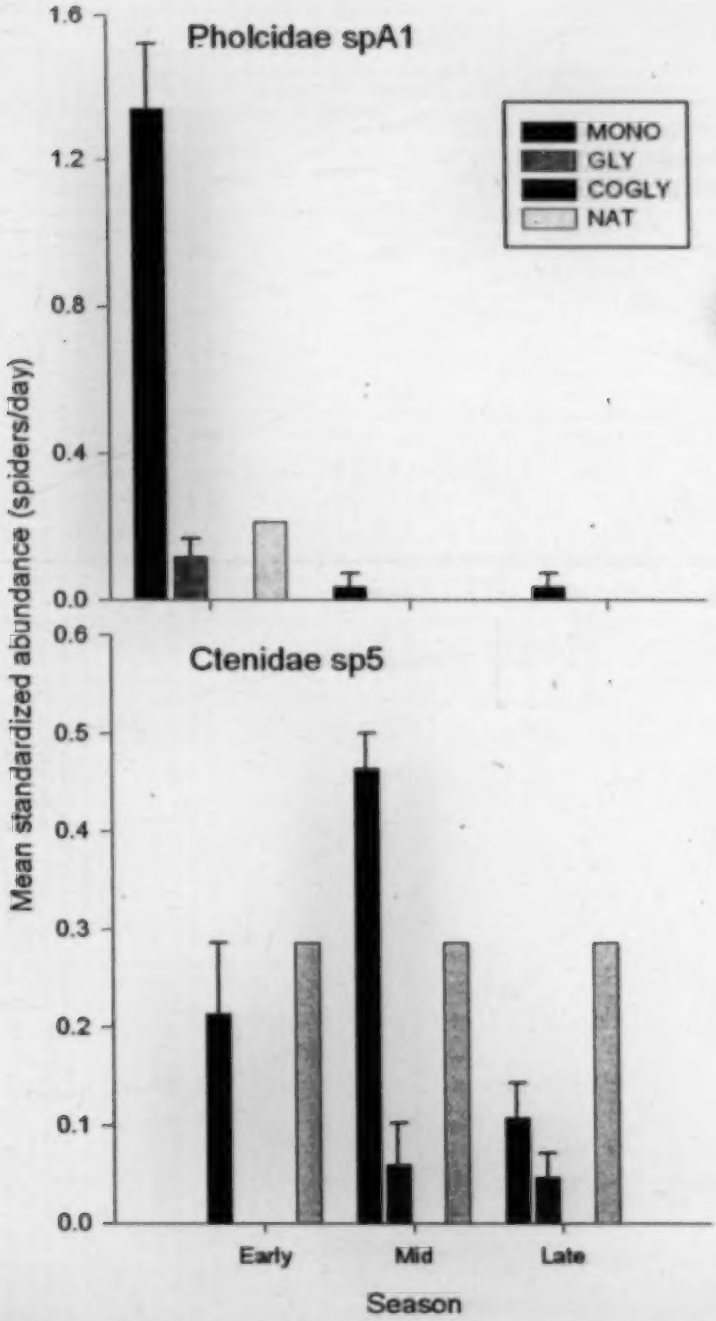

Figure 3-6. Mean standardized abundance of two species with showing significant interactions between cropping systems and seasons. MONO-Monoculture, GLY-Glyricidia, COGLY-Coconut-Glyricidia, NAT-Natural.

Discussion

Both tropical (Romero and Vasconcellos-Neto 2003) and boreal (Niemelä *et al.* 1994) spider assemblages show seasonal differences in peak abundance. In this chapter, I have shown that tropical spider assemblages in North Sulawesi show an important seasonal element with respect to abundance of common species. Seasonal changes may affect presence or absence of species at particular times (Norris 1999). Residence time of spiders with limited dispersal abilities such as web builders is influenced by disturbance or habitat destruction (McNett and Rypstra 2000). Furthermore, seasonality in tropical spiders was influenced by cropping system or habitat structure. The present study emphasizes the importance of sampling time which is related to seasons and habitat structure in monitoring seasonal patterns of spiders. The work illustrates that time of sampling was crucial for monitoring seasonal patterns in spider abundance.

Seasonal patterns of spider abundance and species

Temporal patterns in the abundance of spiders probably reflect seasonal variation of the environment with respect to rainfall. Although rainy and dry seasons in North Sulawesi are less pronounced than elsewhere in the tropics, this study revealed that spiders generally had seasonal abundance patterns with the highest abundance in the early rainy season, and reduced abundance during and following the rainy season.

The four most abundant species also showed similar seasonal abundance patterns. In the early rainy season these species were able to maintain their populations, perhaps because there was no disturbance or little habitat change caused by an abiotic factor such as rainfall. The fine sheet-web of hahniids, space webs of pholcids, and irregular mesh of strands of linyphiids that attached to ground vegetation layers may be damaged during the rainy season when rainfall reaches a peak. Web destruction can affect the source of food (prey availability) for spiders with limited dispersal ability such as web-builders, thus their population decreased during the rainy season. That trend continued in the

late season may indicate increased mortality among food-limited spiders. Also, these spiders need time to reconstruct their new webs on ground vegetation that provides suitable web-attachment sites after the rainy season, their absence may be more apparent than real. As for gnaphosids, flooding of retreats or hiding places on the ground may affect the hunting ability/strategy of ground dwellers to catch their prey in the mid season; thus population decreased.

Clearly, understanding the probable effect of time of sampling on results will help us make more effective biodiversity assessments. Spiders should be sampled in the early rainy season, and during and following the rainy season to identify the presence or absence species and their seasonal patterns in abundance throughout the seasons (early, mid, and late). Sampling spiders only in the mid or late season will cause a different understanding of the natural state of spiders and how disturbances affect their population. If sampling resources were limited, the best time for sampling would be during the period before the rainy season.

The influence of cropping system in the seasonality in spiders

Spiders are extremely sensitive to small changes in habitat structure (Uetz 1991) and habitat structure has an important influence in determining presence of web-building spiders (Lubin 1978;Uetz 1991; Rypstra *et al.* 1999; Chen and Tso 2004; Tsai *et al.* 2006). Species diversity and web type diversity followed the overall seasonal pattern of spider abundance (Lubin 1978). In general, as disturbance increases the spider species richness decreases (Uetz 1991).

Results of this study demonstrated that changes in habitat structure affect seasonal abundance patterns in spider assemblages. Spiders in the natural habitat (NAT) system had different seasonal abundance patterns compared to spiders in the semi natural (GLY and COGLY) and simplified (MONO) systems. Declining patterns in seasonal abundance of spiders in the most disturbed (MONO system) and semi natural habitats (GLY system) throughout the seasons suggested that spiders were in a disturbed state. Spiders maintained abundance during the rainy season in the NAT system indicating that this system received

no or little disturbance associated with this season. Diversity of natural shade trees in the NAT system support spider diversity and abundance regardless of season.

Interaction of season and system in species abundance indicates that cropping systems affect seasonality in individual species. Presence of web building spiders was influenced by habitat structure. Declining patterns in seasonal abundance of space web-builder Pholcidae spA1 in the most disturbed habitat (MONO) system indicate that changes in habitat structure affect the abundance of this species. Pholcidae spA1 populations might be in a disturbed state because in the semi natural habitat (GLY) and natural habitat (NAT) systems, they were only present in the early rainy season, then absent both during and following the rainy season. Nocturnal wandering spiders such as Ctenidae sp5 responded differently to changes in habitat structure. Stable seasonal patterns in species abundance throughout the seasons in the NAT system indicate that this system received no disturbance because Ctenidae sp5 were doing very well. In the GLY system, Ctenidae sp5 were absent in the early rainy season, and present with a very low abundance during and following the rainy season. Both Pholcidae spA1 and Ctenidae sp5 were absent in the semi natural (COGLY) system, suggesting that the GLY system is better than the COGLY system in maintaining spider species abundance. The physical structure of coconut trees (e.g., tall and straight trunks without branches) also may not provide sufficient canopy shade for cacao cultivation.

Implications for conservation of biodiversity

Understanding seasonality is relevant to biodiversity conservation in tropical regions. The present study emphasizes the importance of sampling time which is related to season and habitat structure (cropping systems) in monitoring seasonal patterns of spiders. Information from this study provides useful insight into the natural history of tropical spiders. For example, the abundance of species permanently occurring in a community can be used as a diagnostic tool to assess the natural state of tropical spider assemblages (Relys *et al.* 2002).

Absence of such species or finding that their populations were lower than typical baseline abundance, as tempered by information about seasonal fluctuations, can indicate disturbance of the community. Increases in richness and abundance of species typical of other habitats will suggest the occurrence of changes in living conditions for a particular tropical spider assemblage. The present study was conducted in early to late rainy season or the early dry season (September 2001-May 2002). Therefore, to get a true picture of the seasonal patterns of tropical spider assemblages, sampling should be collected in both rainy and dry seasons over extended years. Management conservation of spiders in their existing habitats can be design, apply, and evaluate by sampling in timely manner. However, if resources are limited, sampling spiders should be conducted in early rainy season.

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Chapter 4 General Discussion

In this thesis I underscore the importance of agroforestry systems used for cacao production as a strategy to conserve tropical spider assemblages in Indonesia. I have also shown that spider abundance has seasonal patterns that vary with habitat in North Sulawesi and used these data to suggest the best sampling times for use of spiders as possible indicators of biodiversity changes.

4.1 Main Findings of the Thesis

The first chapter of this thesis highlighted the probable impacts of cacao cropping systems on the diversity and abundance of tropical spiders. Several studies have demonstrated the positive contribution of diverse cropping systems to supporting local biodiversity and the negative effects of simplified monoculture on spider assemblages (Perfecto *et al.* 1996; Rypstra *et al.* 1999; Rice and Greenberg 2000; Siebert 2002; Langellotto and Denno 2004; Philpott and Armbrecht 2006; Philpott *et al.* 2006; Greenberg 2006). My study extends these results to N. Sulawesi, where cacao is a major export crop, and cautions us about the present movement away from agroforestry situations and toward monoculture of sun-tolerant varieties without shade trees or intercrop.

My second chapter examined ground and vegetation-dwelling spider assemblages in four different cacao cropping systems. This study recognized that diversity will increase with an increase in both floristic and structural diversity of the cacao shade level.

As a rule, diversified habitats support more species than simplified habitats (Altieri and Nicholls 1999) and this observation was supported by my study. The most diverse habitat (NAT system) had the highest species richness of vegetation-dwelling spiders (Figure 2-4C). Although ground-dwelling spiders did not follow the same trend (Figure 2-4D), spider taxa showed different responses to the range of habitats studied, suggesting that highly disturbed habitats such as monoculture have significant effects on spider diversity. Furthermore, these findings emphasize that conservation of 'biodiversity' is a landscape issue, fundamentally because different species have different niches and are favoured

by habitats with different histories and characteristics. Although this is a well understood ecological principle, many managers continue to seek some sort of optimum solution achieved by aiming at a universal target.

The COGLY and GLY systems shared similar species composition (Figure 2-6), however the species composition is very different from that in the MONO systems, suggesting that all of these cropping systems can contribute to supporting biodiversity of both vegetation and ground dwelling spiders. Although spider guild composition (Barrion and Litsinger 1995; Uetz *et al.* 1999) differed among the COGLY, GLY, and MONO systems, ground runners were most abundant in my dataset. Open habitats ranging from little to no shade canopies enhanced the growth of ground vegetation layer which provide more hiding and retreat places for ground running spiders. Rich understories, in contrast, are expected to support more web-building spiders in agroforestry systems.

My work suggests that preserving the existing diversity of cacao agroforestry systems in North Sulawesi, Indonesia is the best solution for cacao growers in this region. At a small scale, most of the cacao cultivation in this region are planted under coconut-glyricidia (COGLY) shade. Coconuts are the main agricultural commodity in the province of North Sulawesi which is well known as the land of the coconut. Copra made from coconut flesh are the main ingredient for producing cooking oil which is the common cooking oil use in Indonesia. By preserving the COGLY system, not only will socioeconomic-cultural conflict be minimized, the cropping systems that promote traditional shade approaches to cacao cultivation will maintain some specific environmental benefits such as nutrient cycling and natural pest control through environmental resistance, as well as optimize the diversity of tropical spiders. In the long run, a wholesale move to MONO systems is not recommended for the sake of well being of spider assemblages and overall biodiversity.

My third chapter focuses on seasonal patterns in tropical spider assemblages. This study revealed that tropical spider assemblages (Figure 3-3) and individual species (Figure 3-4) have unexpected differences in seasonal patterns in peak abundance across the seasons, reaching the highest activity

prior to the rainy season, and reduced activity during and following the rainy season. Seasonality in tropical spider assemblages (Figure 3-5) and individual species (Figure 3-6) was also influenced by cropping system. From the seasonal abundance patterns recorded throughout the seasons across three cropping systems, it is clear that spider populations in the natural habitat (NAT) system were not in a disturbed state. However, my data suggest that the assemblages are disturbed in the simplified (MONO) and semi natural habitat (GLY) systems.

Although there is no interaction in abundance of overall spider assemblages between season and system, two individual species showed a strong interaction between season and system. The presence and absence of Pholcidae spA1 and Ctenidae sp5 in particular season across three cropping systems may indicate whether the systems are in a disturbed state or not (Figure 3-6). Climatic change caused by the rainy season in different cropping systems may contribute to the seasonal abundance patterns of spiders (Tanaka and Tanaka 1982; Ward and Lubin 1992; Niemelä *et al.* 1994; Polis *et al.* 1998; Arango *et al.* 2000; Bonte and Mertens 2003, Romero, G.Q. and Vasconcellos-Netto 2003; Langlands *et al.* 2006).

My work suggests that understanding of seasonal patterns is crucial for investigating the natural history of spiders. Furthermore, information about the natural history of the presently stable species in a community will be a fundamental asset for biomonitoring changes in spider assemblages. Changes in diversity and abundance of the most stable species in the community is an indication whether a community is in a disturbed state or not (Relys *et al.* 2002). Normal residence times of spider species must be understood in order to design sampling programs that will describe a true picture of the community. Further understanding of the factors that determine seasonal patterns in tropical spider assemblages will enhance our ability to predict the impacts of disturbances on spider communities.

4.2 Importance of Agroforestry Systems

It is clear that conversion of the traditional forest cacao farms to intensive, full-sun monocultures can have negative impacts on overall biodiversity and spider assemblages. Agroforestry practices in cacao cultivation in North Sulawesi, Indonesia affect spider diversity and abundance, and species and guild composition. Therefore, these practices must be maintained for the conservation of overall biodiversity.

4.3 Importance of Taxa

The taxonomic resources available for study of the spider fauna in North Sulawesi, Indonesia are inadequate for serious scientific work. This resulted in the requirement for me to treat many specimens as belonging to undescribed morphospecies (see Appendix 4-1). Scientific names and their basis in information retrieval are crucial to the accurate study of biological diversity of organisms. All information including the natural history, life cycle, and ecological factors that influence particular taxa are catalogued under the species name. Cacao plantations in this region may be important for conserving certain species which are able to adapt to changes across the habitat gradient from the natural shade trees cacao systems to highly modified sun monoculture systems. Therefore, taxonomy to ensure the reliable and repeatable use of names to focus on these species will help us to gain a better understanding of the impact of habitat disturbances on their population.

4.5 Management recommendations and future research

Multidisciplinary studies of cacao agroforestry systems are needed to quantify ecological losses and socioeconomic tradeoffs under different management options. Some of these have been conducted in Central Sulawesi, Indonesia (Steffan-Dewenter *et al.* 2007). However, spiders were not included among the nine plant and animal taxa that they investigated. Research available on the Indonesian spider fauna is in its early stages, with efforts devoted primarily to species and faunal description (Brignoli 1980; Bosmans and Hillyard

1990; Bosmans 1992; Millidge and Russell-Smith 1992; Russell-Smith and Stork 1994).

It is clear from this thesis and research presented elsewhere that traditional shade cacao agroforestry system is one of the few productive agricultural systems that can sustain a diverse tropical assemblages of arthropods. There is a need to evaluate the shade-tree species best suited to create a habitat supportive of conservation of overall biodiversity. In the case of cacao agroforestry systems in North Sulawesi, existing data suggest that the natural shade-tree (NAT) system had the highest diversity of vegetation-dwelling spiders and that this cropping system should continue to be used. Semi-natural habitats such as COGLY and GLY cropping systems showed no difference in species diversity, suggesting that coconut trees did not make any difference to spider diversity. Replacing coconut trees with other trees from these systems surely will cause a big problem among cacao growers since coconuts are the main agricultural product of this region, providing cash value two to three times a year. Spider diversity might be boosted by introducing one or two tree additional species with additional economic value into the existing COGLY and GLY systems. Research on such systems should be continued for at least two consecutive years in the existing cacao agroforestry systems with a balanced and fully replicated design.

The significance of seasonality in tropical spider assemblages cannot be fully evaluated at this time due to the relatively short duration of my study. However, it is clear that tropical spider assemblages showed seasonal peak abundance patterns in the rainy season. There is a need to study the natural history of spider species in cacao agroforestry systems in both rainy and dry seasons over extended years (minimum 2 years) to develop baseline data for the particular spider species present in their habitats. For this research, firstly, there is a need to identify spider species in each cacao system. Resources such as keys to support identification and taxonomic specialists will be required to identify the spider specimens at least in of the generic level. Secondly, biomonitoring of these species in relation to environmental changes can be done by investigating

residence times of selected species. Sampling of spiders must be done in a way that allows species with different daily and seasonal activity programs to be included in the sample.

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Appendix 4-1 Taxonomic composition of the spiders recorded from the cacao agroforestry systems in North Sulawesi, Indonesia (2001-2002)

Family	Species	Guild	Pitfall	Sweep
Araneidae	*Araneidae sp1*	Orb-weavers	Absent	Present
	Araneidae sp2	Orb-weavers	Absent	Present
	Araneidae sp3	Orb-weavers	Absent	Present
	Araneidae sp4	Orb-weavers	Absent	Present
	Araneidae sp5	Orb-weavers	Absent	Present
	Araneidae sp6	Orb-weavers	Absent	Present
	Araneidae sp7	Orb-weavers	Absent	Present
	Araneidae sp8	Orb-weavers	Absent	Present
	Araneidae sp9	Orb-weavers	Absent	Present
	Araneidae sp10	Orb-weavers	Present	Present
	Araneidae sp11	Orb-weavers	Absent	Present
	Araneidae sp12	Orb-weavers	Absent	Present
	Araneidae sp13	Orb-weavers	Absent	Present
	Araneidae sp14	Orb-weavers	Absent	Present
	Araneidae sp15	Orb-weavers	Absent	Present
	Araneidae sp16	Orb-weavers	Absent	Present
	Araneidae sp17	Orb-weavers	Absent	Present
	Araneidae sp18	Orb-weavers	Absent	Present
	Araneidae sp19	Orb-weavers	Absent	Present
	Araneidae sp20	Orb-weavers	Absent	Present
	Araneidae sp21	Orb-weavers	Absent	Present
	Araneidae sp22	Orb-weavers	Absent	Present
	Araneidae sp23	Orb-weavers	Absent	Present
	Araneidae sp24	Orb-weavers	Absent	Present
	Araneidae sp25	Orb-weavers	Absent	Present
	Araneidae sp26	Orb-weavers	Present	Absent
	Araneidae sp27	Orb-weavers	Present	Absent
	Argiope sp1	Orb-weavers	Present	Present

Family	Species	Guild	Pitfall	Sweep
	Argiope sp2	Orb-weavers	Absent	Present
	Argiope sp3	Orb-weavers	Absent	Present
	Argiope sp4	Orb-weavers	Absent	Present
	Argiope sp5	Orb-weavers	Absent	Present
	Argiope sp6	Orb-weavers	Absent	Present
	Argiope aemuela (Walckenaer)	Orb-weavers	Absent	Present
	Argiope pulchelloides Yin *et al.*	Orb-weavers	Present	Present
	Argiope sapoa Barrion&Litsinger	Orb-weavers	Absent	Present
	Cyclosa baakea Barrion&Litsinger	Orb-weavers	Present	Present
	Cyclosa dosbukolea Barrion&Lit	Orb-weavers	Absent	Present
	Cyrtophora sp1	Orb-weavers	Absent	Present
	Cyrtophora unicolor (Doleschall)	Orb-weavers	Absent	Present
	Gasteracantha sp1	Orb-weavers	Present	Present
	Gasteracantha sp2	Orb-weavers	Present	Present
	Neoscona sp1	Orb-weavers	Absent	Present
	Neoscona yptinika Barrion&Litsinger	Orb-weavers	Absent	Present
	Neoscona menghaiensis Yin et al.	Orb-weavers	Absent	Present
	Neoscona usbonga Barrion&Lit	Orb-weavers	Absent	Present
	Neoscona jinghongensis Yin *et al.*	Orb-weavers	Absent	Present
	Nephila maculata (Fabricius)	Orb-weavers	Present	Present
	Nephila antipodiana (Walckenaer)	Orb-weavers	Absent	Present
	Nephila pilipes (Fabricius)	Orb-weavers	Absent	Present
	Parawixia dehaani (Doleschall)	Orb-weavers	Present	Present
	Tukaraneus mahabaeus Barrion&Lit	Orb-weavers	Absent	Present
	Tukaraneus sp1	Orb-weavers	Absent	Present
	Tukaraneus sp2	Orb-weavers	Absent	Present
Tetragnathidae	*Leucauge sp1*	Orb-weavers	Absent	Present
	Leucauge sp2	Orb-weavers	Absent	Present
	Leucauge sp3	Orb-weavers	Absent	Present
	Leucauge sp4	Orb-weavers	Absent	Present
	Leucauge decorata (Blackwall)	Orb-weavers	Absent	Present

Family	Species	Guild	Pitfall	Sweep
	Leucauge fastigata (Simon)	Orb-weavers	Present	Present
	Leucauge mahabascapea Barrion&Lit	Orb-weavers	Absent	Present
	Leucauge subgemmea Bosenberg et Strand	Orb-weavers	Absent	Present
	Tetragnatha sp1	Orb-weavers	Absent	Present
	Tetragnatha sp2	Orb-weavers	Absent	Present
	Tetragnatha sp3	Orb-weavers	Absent	Present
	Tetragnatha sp4	Orb-weavers	Absent	Present
	Tetragnatha sp5	Orb-weavers	Absent	Present
	Tetragnatha sp6	Orb-weavers	Absent	Present
	Tetragnatha mandibulata Walckenaer	Orb-weavers	Absent	Present
	Tylorida striata Thorell	Orb-weavers	Absent	Present
	Tylorida ventralis Thorell	Orb-weavers	Absent	Present
Theridiidae	*Achaearanea spA1*	Space web-builders	Absent	Present
	Achaearanea spA2	Space web-builders	Absent	Present
	Achaearanea spA3	Space web-builders	Absent	Present
	Achaearanea spB1	Space web-builders	Absent	Present
	Achaearanea spB2	Space web-builders	Absent	Present
	Achaearanea spB3	Space web-builders	Absent	Present
	Achaearanea spB4	Space web-builders	Absent	Present
	Achaearanea spC	Space web-builders	Absent	Present
	Achaearanea spD	Space web-builders	Absent	Present
	Achaearanea spE	Space web-builders	Absent	Present
	Achaearanea spF	Space web-builders	Absent	Present
	Argyrodes spB	Space web-builders	Absent	Present
	Argyrodes spC	Space web-builders	Absent	Present
	Chrysso spA1	Space web-builders	Absent	Present
	Chrysso spA2	Space web-builders	Absent	Present
	Chrysso spB	Space web-builders	Absent	Present
	Chrysso spC	Space web-builders	Present	Absent
	Episinus spA	Space web-builders	Absent	Present

Family	Species	Guild	Pitfall	Sweep
	Theridion spA	Space web-builders	Absent	Present
	Theridion spB	Space web-builders	Present	Absent
	Hadrotarsinae spA1	Space web-builders	Absent	Present
	Hadrotarsinae spA2	Space web-builders	Present	Absent
	Hadrotarsinae spB	Space web-builders	Present	Absent
	Hadrotarsinae spC	Space web-builders	Present	Absent
	Theridiidae spA	Space web-builders	Absent	Present
	Theridiidae spB	Space web-builders	Absent	Present
	Theridiidae spC	Space web-builders	Absent	Present
Mysmenidae	*Mysmenella spA1*	Space web-builders	Present	Absent
	Mysmenella spA2	Space web-builders	Present	Absent
Linyphiidae	*Linyphiidae spA1*	Wandering sheet	Present	Absent
	Linyphiidae spA2	Wandering sheet	Present	Absent
	Linyphiidae spA3	Wandering sheet	Present	Absent
	Linyphiidae spB1	Wandering sheet	Present	Absent
	Linyphiidae spB2	Wandering sheet	Present	Absent
	Linyphiidae spB3	Wandering sheet	Present	Absent
	Linyphiidae sp3	Wandering sheet	Present	Absent
	Linyphiidae sp4	Wandering sheet	Present	Absent
	Linyphiidae sp9	Wandering sheet	Present	Absent
	Linyphiidae sp10	Wandering sheet	Present	Absent
	Linyphiidae sp15	Wandering sheet	Present	Absent
	Linyphiidae sp20	Wandering sheet	Present	Absent
	Linyphiidae sp23	Wandering sheet	Present	Absent
	Neonesites spA1	Wandering sheet	Present	Absent
	Neonesites spA2	Wandering sheet	Present	Absent
	Neonesites spA3	Wandering sheet	Present	Absent
Salticidae	*Salticidae sp1*	Stalkers/Ambushers	Absent	Present
	Salticidae sp2	Stalkers/Ambushers	Absent	Present
	Salticidae sp3	Stalkers/Ambushers	Absent	Present
	Salticidae sp4	Stalkers/Ambushers	Absent	Present

Family	Species	Guild	Pitfall	Sweep
	Salticidae sp5	Stalkers/Ambushers	Absent	Present
	Salticidae sp6	Stalkers/Ambushers	Absent	Present
	Salticidae sp7	Stalkers/Ambushers	Absent	Present
	Salticidae sp8	Stalkers/Ambushers	Absent	Present
	Salticidae sp9	Stalkers/Ambushers	Absent	Present
	Salticidae sp10	Stalkers/Ambushers	Absent	Present
	Salticidae sp11	Stalkers/Ambushers	Absent	Present
	Salticidae sp12	Stalkers/Ambushers	Absent	Present
	Salticidae sp13	Stalkers/Ambushers	Absent	Present
	Salticidae sp14	Stalkers/Ambushers	Absent	Present
	Salticidae sp15	Stalkers/Ambushers	Absent	Present
	Salticidae sp16	Stalkers/Ambushers	Absent	Present
	Salticidae sp17	Stalkers/Ambushers	Absent	Present
	Salticidae sp18	Stalkers/Ambushers	Present	Present
	Salticidae sp19	Stalkers/Ambushers	Absent	Present
	Salticidae sp20	Stalkers/Ambushers	Absent	Present
	Salticidae sp21	Stalkers/Ambushers	Absent	Present
	Salticidae sp22	Stalkers/Ambushers	Absent	Present
	Salticidae sp23	Stalkers/Ambushers	Absent	Present
	Salticidae sp24	Stalkers/Ambushers	Absent	Present
	Salticidae sp25	Stalkers/Ambushers	Absent	Present
	Salticidae sp26	Stalkers/Ambushers	Present	Present
	Salticidae sp27	Stalkers/Ambushers	Absent	Present
	Salticidae sp28	Stalkers/Ambushers	Absent	Present
	Salticidae sp29	Stalkers/Ambushers	Present	Present
	Salticidae sp30	Stalkers/Ambushers	Present	Present
	Salticidae sp31	Stalkers/Ambushers	Absent	Present
	Salticidae sp32	Stalkers/Ambushers	Absent	Present
	Salticidae sp33	Stalkers/Ambushers	Present	Present
	Salticidae sp34	Stalkers/Ambushers	Absent	Present
	Salticidae sp35	Stalkers/Ambushers	Present	Present

Family	Species	Guild	Pitfall	Sweep
	Salticidae sp36	Stalkers/Ambushers	Absent	Present
	Salticidae sp37	Stalkers/Ambushers	Absent	Present
	Salticidae sp38	Stalkers/Ambushers	Absent	Present
	Salticidae sp39	Stalkers/Ambushers	Present	Present
	Salticidae sp40	Stalkers/Ambushers	Present	Present
	Salticidae sp41	Stalkers/Ambushers	Absent	Present
	Salticidae sp42	Stalkers/Ambushers	Absent	Present
	Salticidae sp43	Stalkers/Ambushers	Absent	Present
	Salticidae sp44	Stalkers/Ambushers	Present	Absent
	Salticidae sp45	Stalkers/Ambushers	Absent	Present
	Salticidae sp46	Stalkers/Ambushers	Absent	Present
	Salticidae sp47	Stalkers/Ambushers	Absent	Present
	Salticidae sp48	Stalkers/Ambushers	Present	Present
	Salticidae sp49	Stalkers/Ambushers	Absent	Present
	Salticidae sp51	Stalkers/Ambushers	Absent	Present
	Salticidae sp52	Stalkers/Ambushers	Absent	Present
	Salticidae sp53	Stalkers/Ambushers	Absent	Present
	Salticidae sp54	Stalkers/Ambushers	Present	Absent
	Salticidae sp55	Stalkers/Ambushers	Present	Absent
	Epeus hawigalboguttatus Barrion&Lit	Stalkers/Ambushers	Absent	Present
	Thorelliola ensifera (Thorell)	Stalkers/Ambushers	Present	Present
	Viciria sp1	Stalkers/Ambushers	Absent	Present
Clubionidae	*Clubionidae sp1*	Foliage runners	Absent	Present
	Clubionidae sp2	Foliage runners	Present	Absent
	Clubionidae sp3	Foliage runners	Absent	Present
	Clubionidae sp4	Foliage runners	Absent	Present
	Clubionidae sp5	Foliage runners	Present	Absent
	Clubionidae sp6	Foliage runners	Absent	Present
	Clubionidae sp7	Foliage runners	Absent	Present
	Clubionidae sp8	Foliage runners	Absent	Present
	Clubionidae sp9	Foliage runners	Present	Absent

Family	Species	Guild	Pitfall	Sweep
	Clubionidae sp10	Foliage runners	Present	Absent
	Clubionidae sp11	Foliage runners	Present	Absent
	Clubionidae sp12	Foliage runners	Present	Absent
	Clubiona sp1	Foliage runners	Absent	Present
	Clubiona sp2	Foliage runners	Absent	Present
	Castianeira sp1	Foliage runners	Absent	Present
	Cheirachantium sp1	Foliage runners	Absent	Present
	Cheirachantium sp2	Foliage runners	Absent	Present
	C. adjacensoides Song, Chen *et* Hou	Foliage runners	Absent	Present
	Phrurolithus ulopatulisus Barrion &Lit	Foliage runners	Present	Absent
Philodromidae	*Philodromidae sp1*	Stalkers/Ambushers	Present	Present
	Philodromidae sp2	Stalkers/Ambushers	Present	Present
	Philodromidae sp3	Stalkers/Ambushers	Present	Present
	Philodromidae sp4	Stalkers/Ambushers	Absent	Present
	Philodromidae sp5	Stalkers/Ambushers	Absent	Present
	Philodromidae sp6	Stalkers/Ambushers	Present	Absent
	Philodromidae sp7	Stalkers/Ambushers	Absent	Present
	Philodromidae sp8	Stalkers/Ambushers	Absent	Present
	Philodromidae sp9	Stalkers/Ambushers	Present	Present
	Philodromidae sp10	Stalkers/Ambushers	Absent	Present
	Philodromidae sp11	Stalkers/Ambushers	Present	Absent
	Philodromidae sp12	Stalkers/Ambushers	Present	Absent
	Philodromus sp1	Stalkers/Ambushers	Present	Present
Thomisidae	*Thomisidae sp1*	Stalkers/Ambushers	Absent	Present
	Thomisidae sp2	Stalkers/Ambushers	Present	Present
	Thomisidae sp3	Stalkers/Ambushers	Present	Present
	Thomisidae sp4	Stalkers/Ambushers	Absent	Present
	Thomisidae sp5	Stalkers/Ambushers	Absent	Present
	Thomisidae sp6	Stalkers/Ambushers	Absent	Present
	Thomisidae sp7	Stalkers/Ambushers	Absent	Present
	Thomisus sp1	Stalkers/Ambushers	Present	Present

Family	Species	Guild	Pitfall	Sweep
	Thomisus sp2	Stalkers/Ambushers	Absent	Present
	Diaea sp1	Stalkers/Ambushers	Absent	Present
	Monaeses aciculus (Simon)	Stalkers/Ambushers	Absent	Present
	Runcinia albostriata Boes and Strand	Stalkers/Ambushers	Absent	Present
Ctenidae	*Ctenidae sp1*	Ground runners	Present	Absent
	Ctenidae sp2	Ground runners	Present	Absent
	Ctenidae sp3	Ground runners	Present	Absent
	Ctenidae sp4	Ground runners	Present	Absent
	Ctenidae sp5	Ground runners	Present	Absent
	Ctenidae sp6	Ground runners	Present	Absent
	Ctenidae sp7	Ground runners	Present	Absent
	Ctenidae sp8	Ground runners	Present	Absent
Gnaphosidae	*Gnaphosidae sp1*	Ground runners	Present	Absent
	Gnaphosidae sp2	Ground runners	Present	Present
	Gnaphosidae sp3	Ground runners	Present	Absent
	Gnaphosidae sp4	Ground runners	Present	Absent
	Gnaphosidae sp5	Ground runners	Present	Absent
	Gnaphosidae sp6	Ground runners	Present	Absent
	Gnaphosidae sp7	Ground runners	Present	Absent
	Gnaphosidae sp8	Ground runners	Present	Absent
	Micaria siniloana Barrion&Litsinger	Stalkers/Ambushers	Absent	Present
Oxyopidae	*Oxyopidae sp1*	Stalkers/Ambushers	Absent	Present
Oxyopidae	*Oxyopes sp1*	Stalkers/Ambushers	Absent	Present
	Oxyopes bikakaeus Barrion&Litsinger	Stalkers/Ambushers	Present	Present
	Oxyopes javanus Thorell	Stalkers/Ambushers	Absent	Present
	Oxyopes sikkimensis Tikader	Stalkers/Ambushers	Absent	Present
	Oxyopes striagatus Song	Space web-builders	Present	Present
Pholcidae	*Pholcidae sp1*	Space web-builders	Absent	Present
	Pholcidae sp2	Space web-builders	Absent	Present
	Pholcidae sp3	Space web-builders	Absent	Present
	Pholcidae sp4			

Family	Species	Guild	Pitfall	Sweep
	Pholcidae sp5	Space web-builders	Absent	Present
	Pholcidae sp6	Space web-builders	Absent	Present
	Pholcidae spA1	Space web-builders	Absent	Present
Lycosidae	*Lycosidae sp1*	Ground runners	Present	Absent
	Lycosidae sp2	Ground runners	Absent	Present
	Lycosidae sp3	Ground runners	Present	Absent
	Lycosidae sp4	Ground runners	Present	Present
	Lycosidae sp5	Ground runners	Present	Absent
	Lycosidae sp6	Ground runners	Present	Absent
	Lycosidae spA1	Ground runners	Present	Present
	Lycosidae spA2	Ground runners	Present	Absent
	Lycosidae spB	Ground runners	Present	Absent
	Pardosa birmanica Simon	Ground runners	Present	Absent
	Trochosa aquatica Tanaka	Ground runners	Present	Absent
Oonopidae	*Oonopidae sp1*	Ground runners	Present	Absent
	Oonopidae sp2	Ground runners	Present	Absent
	Oonopidae sp3	Ground runners	Present	Absent
	Oonopidae sp4	Ground runners	Present	Absent
	Oonopidae sp5	Ground runners	Present	Absent
	Oonopidae sp6	Ground runners	Present	Absent
	Oonopidae sp7	Ground runners	Present	Absent
Mimetidae	*Mimetidae sp1*	Stalkers/Ambushers	Present	Absent
	Mimetidae sp2	Stalkers/Ambushers	Present	Absent
	Mimetidae sp3	Stalkers/Ambushers	Present	Absent
	Mimetidae sp4	Stalkers/Ambushers	Present	Absent
	Mimetidae sp5	Stalkers/Ambushers	Present	Absent
	Mimetidae sp6	Stalkers/Ambushers	Present	Absent
Zodariidae	*Zodariidae sp1*	Ground runners	Present	Absent
	Zodariidae sp2	Ground runners	Present	Absent
	Zodariidae sp3	Ground runners	Present	Absent
	Zodariidae sp4	Ground runners	Present	Absent

Family	Species	Guild	Pitfall	Sweep
Pisauridae	*Pisaura sp1*	Stalkers/Ambushers	Absent	Present
	Pisauridae sp1	Stalkers/Ambushers	Absent	Present
	Pisauridae sp2	Stalkers/Ambushers	Absent	Present
Corinnidae	*Corinnidae sp1*	Ground runners	Present	Absent
	Corinnidae sp2	Ground runners	Present	Absent
Scytodidae	*Scytodidae sp1*	Foliage runners	Absent	Present
	Scytodidae sp2	Foliage runners	Absent	Present
	Scytodes thoracica (Latreille)	Foliage runners	Absent	Present
Heteropodidae	*Heteropoda squamacea* Wang	Foliage runners	Present	Absent
Theraphosidae	*Theraphosidae sp1*	Wandering sheet	Present	Absent
Cryptothelidae	*Cryptothele sundaica* L. Koch	Ground runners	Present	Absent
Dictynidae	*Dictynidae sp1*	Space web-builders	Absent	Present
Psechridae	*Psechridae sp1*	Space web-builders	Absent	Present
Agelenidae	*Agelenidae sp1*	Sheet web-builders	Present	Absent
Hahniidae	*Hahniidae sp1*	Sheet web-builders	Present	Absent
Dipluridae	*Dipluridae sp1*	Sheet web-builders	Present	Absent
Uloboridae	*Uloboridae sp1*	Orb-weavers	Absent	Present
Amaurobiidae	*Amaurobidae sp1*	Sheet web-builders	Absent	Present